THE No 1 UK MAGAZINE FOR ELECTRONICS TECHNOLOGY & COMPUTER PROJECTS

EPE EVERYDAY PRACTICAL ELECTRONICS

www.epemag.com

WIN A MICROCHIP BM64 Bluetooth Audio Evaluation Board

ARDUINO MULTIFUNCTION 24-BIT MEASURING SHIELD

- PC-linked digital measurement system
- Four 24-bit DC voltmeter ranges
- Audio level and power meter
- RF level and power meter

BATTERY PACK CELL BALANCER

Optimise your battery charging circuits

MICROWAVE LEAKAGE DETECTOR

Don’t get zapped – test your oven!

MICROCHIP EXCLUSIVE OFFER

Check out our AMAZING offer – see page 5

MICROCHIP
www.microchipDIRECT.com

MEET THE MIGHTY MICROMITE

Part 3 – Program your Micromite
with MMBasic

APRIL 2017 £4.40

AUDIO OUT, PIC n’ MIX, COOL BEANS,
TECHNO TALK, NET WORK, CIRCUIT SURGERY,
ELECTRONIC BUILDING BLOCKS & INGENUITY UNLIMITED

FUZE

FUZE Special Edition

- Protect your Pi from physical & static damage
- UK keyboard & Mouse
- FUZE I/O Board with 40 way GPIO pass-through
- Clearly labelled input output ports
- 3 Amp power supply and on/off switch!
- Adds analogue ports, 4 in & 1 out
- 840 pin solderless breadboard (black)
- 8GB SD pre-configured with FUZE BASIC

THE NATIONAL MUSEUM OF COMPUTING "The FUZE is what the Raspberry Pi was designed for"

micro mart EDITOR'S CHOICE ... it's certainly the best we've ever tested

PC PRO Recommended ...makes the Pi more accessible than ever

from £99.99

FUZE Technologies Ltd
+44 (0) 1844 239 432 - contact@fuze.co.uk

Available from www.fuze.co.uk

QUICKDRONES

- 100% ready to fly. From box to air takes seconds
- Unified body design & incredibly durable
- 700TVL camera provides excellent FPV picture
- 2205 2300KV powerful motor
- Status LED to show battery & transmission channel
- One button to switch video channel & power
- DVR port for onboard recording
- Low battery & out of sight warning buzzer
- Available in various colours

The *VIFLY* R220 is a 100% ready-to-fly FPV Racing Drone, no assembly, no calibration, just fly it out of the box. The robust design protects the electrical components inside the frame and gives it an incredible ability to withstand violent crashes. The 3 digit LED display shows the battery voltage and a single button switches video transmission channel and power output. The addition of a DVR port and warning buzzer, makes flying the VIFLY R220 FPV drone easier than ever.

price £349.99

Including VAT and UK delivery

BinaryDistribution Ltd
+44 (0) 1844 239 432 - admin@binarydistribution.co.uk

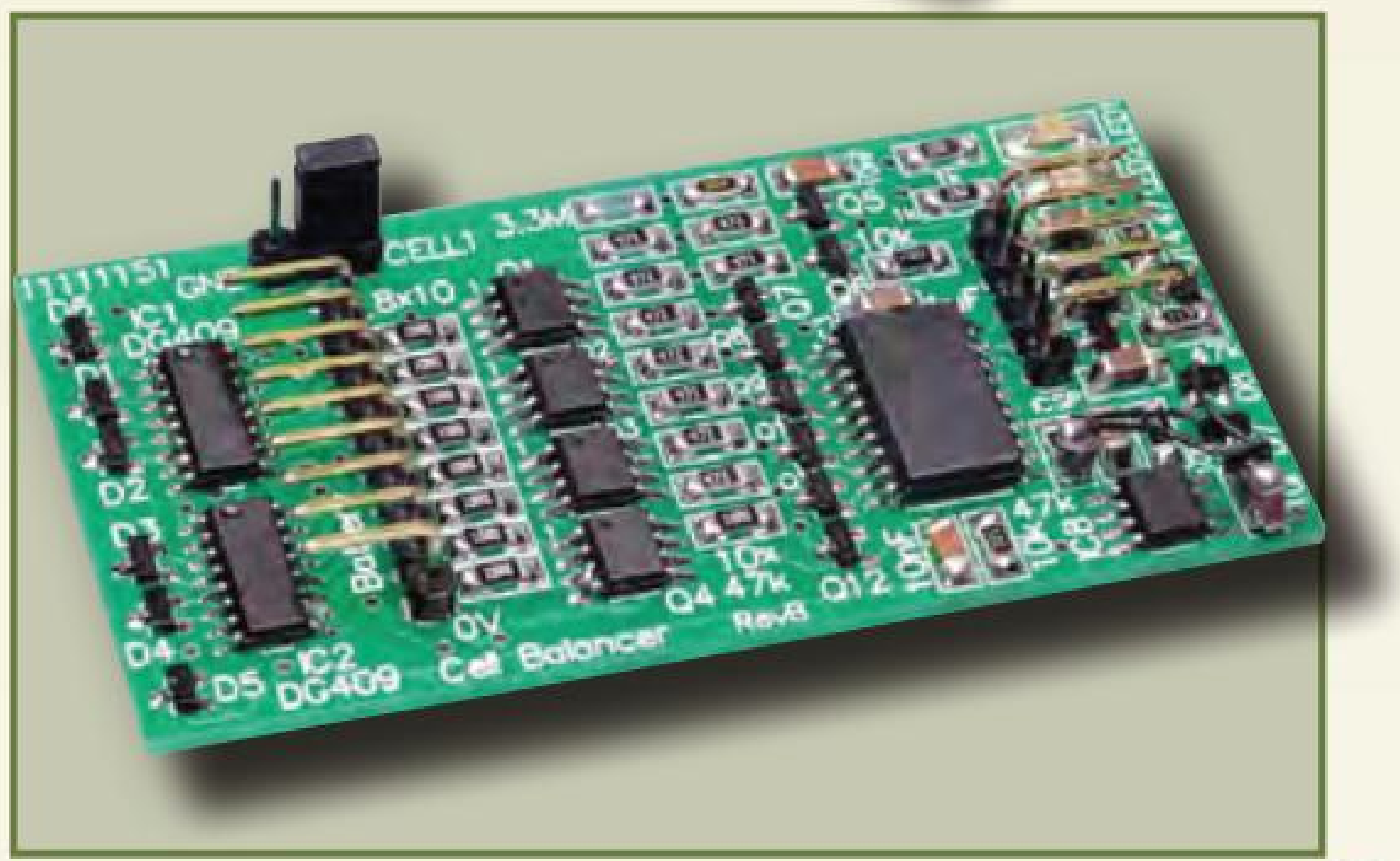
www.quickdrones.co.uk

ISSN 0262 3617
● PROJECTS ● THEORY ●
● NEWS ● COMMENT ●
● POPULAR FEATURES ●
VOL. 46. No. 4 April 2017

EPE EVERYDAY PRACTICAL ELECTRONICS

INCORPORATING ELECTRONICS TODAY INTERNATIONAL

www.epemag.com



Meet the mighty
Micromite
Part 3: Programming
the Micromite in MMBasic

Projects and Circuits

MICROWAVE LEAKAGE DETECTOR 12
by Nicholas Vinen
Is your oven leaking microwave energy, potentially putting you at risk of being zapped? Now you can easily test it!

ARDUINO MULTIFUNCTION 24-BIT MEASURING SHIELD 18
by Jim Rowe
Superb PC-linked measuring system with audio frequency level/power meter, plus an optional RF level/power meter that can operate to 500MHz.

BATTERY PACK CELL BALANCER 28
by Nicholas Vinen
This small board balances the charge between individual cells, avoiding incomplete charging and premature failure.

INGENUITY UNLIMITED 49
Inexpensive DC multi-voltage reference... Steam train sound simulator

Series and Features

TECHNO TALK by Mark Nelson 11
Zero value – but not valueless!

MEET THE MIGHTY MICROMITE 38
by Geoff Graham
Part 3: Programming the Micromite in MMBasic

NET WORK by Alan Winstanley 44
Dell Downloads... Fighting Fitbit... Fire power

PIC n' MIX by Mike O'Keeffe 46
PICs and the PICkit 3: LED Binary Clock – Part 2

CIRCUIT SURGERY by Ian Bell 52
Variable voltage PWM

AUDIO OUT by Jake Rothman 56
Book reviews – DIY Loudspeaker Building... Learning the Art of Electronics – A Hands-on Lab Course

MAX'S COOL BEANS by Max The Magnificent 58
The nth sense... Flexing the old gray matter

ELECTRONIC BUILDING BLOCKS by Julian Edgar 66
New control system for a spot welder

Regulars and Services

SUBSCRIBE TO *EPE* and save money 4

***EPE* – MICROCHIP SPECIAL OFFER – NOT TO BE MISSED!** 5

EDITORIAL 7
What will you do with Micromite?... Jam tomorrow

NEWS – Barry Fox highlights technology's leading edge 8
Plus everyday news from the world of electronics

MICROCHIP READER OFFER 17
EPE Exclusive – Win a Microchip BM64 Bluetooth Audio Evaluation Board

EPE BACK ISSUES CD-ROM 27

EPE BACK ISSUES 36

EPE TEACH-IN 7 59

***EPE* CD ROMS FOR ELECTRONICS** 60
A wide range of technical books available by mail order, plus more CD-ROMs

DIRECT BOOK SERVICE 64
A wide range of technical books available by mail order, plus more CD-ROMs

***EPE* PCB SERVICE** 70
PCBs for *EPE* projects

ADVERTISERS INDEX 71

NEXT MONTH! – Highlights of next month's *EPE* 72

© Wimborne Publishing Ltd 2017. Copyright in all drawings, photographs and articles published in *EVERYDAY PRACTICAL ELECTRONICS* is fully protected, and reproduction or imitations in whole or in part are expressly forbidden.

Our May 2017 issue will be published on Thursday 6 April 2017, see page 72 for details.

Readers' Services • Editorial and Advertisement Departments 7

QUASAR electronics

Quasar Electronics Limited
PO Box 6935, Bishops Stortford
CM23 4WP, United Kingdom
Tel: 01279 467799
Fax: 01279 267799
E-mail: sales@quasarelectronics.co.uk
Web: www.quasarelectronics.co.uk

All prices INCLUDE 20.0% VAT. Free UK delivery on orders over £35
Postage & Packing Options (Up to 0.5Kg gross weight): **UK Standard 3-7 Day Delivery** - £3.95; **UK Mainland Next Day Delivery** - £8.95; **Europe (EU)** - £12.95; **Rest of World** - £14.95 (up to 0.5Kg).
Order online for reduced price Postage (from just £3)
Payment: **We accept all major credit/debit cards. Make PO's payable to Quasar Electronics Limited.**
Please visit our online shop now for full details of over 1000 electronic kits, projects, modules and publications. Discounts for bulk quantities.

01279 Card Sales & Enquiries 467799

Solutions for Home, Education & Industry Since 1993

PIC & ATMEL Programmers

We have a wide range of low cost PIC and ATMEL Programmers. Complete range and documentation available from our web site.

Programmer Accessories:
40-pin Wide ZIF socket (ZIF40W) £9.95
18Vdc Power supply (661.130UK) £23.95
Leads: Parallel (LDC136) £2.56 | Serial (LDC441) £2.75 | USB (LDC644) £2.14

USB & Serial Port PIC Programmer

USB or Serial connection. Header cable for ICSP. Free Windows software. See website for PICs supported. ZIF Socket & USB lead extra. 16-18Vdc.
*Kit Order Code: 3149EKT - **~~£49.96~~ £23.95***
*Assembled Order Code: AS3149E - **£38.95***
*Assembled with ZIF socket Order Code: AS3149EZIF - **~~£74.96~~ £48.95***

USB PIC Programmer and Tutor Board

The only tutorial project board you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. Programs all the devices a Microchip PICKIT2® can! Use the free Microchip tools for PICKit2™ & MPLAB® IDE environment.
*Order Code: EDU10 - **£46.74***

ATMEL 89xxxx Programmer

Uses serial port and any standard terminal comms program. 4 LED's display the status. ZIF sockets not included. 16Vdc.
*Kit Order Code: 3123KT - **~~£32.95~~ £21.95***
*Assembled ZIF: AS3123ZIF- **~~£48.96~~ £37.96***

Introduction to PIC Programming

Go from complete beginner to burning a PIC and writing code in no time! Includes 49 page step-by-step PDF Tutorial Manual + Programming Hardware (with LED test section) + Windows Software (Program, Read, Verify & Erase) + a rewritable PIC16F84A. 4 detailed examples provided for you to learn from. Parallel port. 12Vdc.
*Kit Order Code: 3081KT - **£17.95***
*Assembled Order Code: AS3081 - **£24.95***

PICKit™2 USB PIC Programmer Module

Versatile, low cost, PICKit™2 Development Programmer. Programs all the devices a Microchip PICKIT2 programmer can. Onboard sockets & ICSP header. USB powered.
*Assembled Order Code: VM203 - **£39.54***

PIC Programmer & Experimenter Board

With test buttons and LED indicators to carry out educational experiments such as the supplied programming examples. Includes a 16F627 Flash Microcontroller that can be reprogrammed up to 1000 times. Software to compile and program your source code is included. Supply: 12-15Vdc. Supplied pre-assembled and ready to use.
*Order Code: VM111 - **~~£38.88~~ £30.54***

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £10.68

USB Experiment Interface Board

Updated Version! 5 digital inputs, 8 digital outputs plus two analogue inputs and two analogue outputs. 8 bit resolution. DLL.
*Kit Order Code: K8055N - **~~£39.95~~ £22.74***
*Assembled Order Code: VM110N - **£39.95***

2-Channel High Current UHF RC Set

State-of-the-art high security. Momentary or latching relay outputs rated to switch up to 240Vac @ 12 Amps. Range up to 40m. 15 Tx's can be learnt by one Rx. Kit includes one Tx (more available separately). 9-15Vdc.
*Kit Order Code: 8157KT - **£44.95***
*Assembled Order Code: AS8157 - **£49.96***

Computer Temperature Data Logger

Serial port 4-ch temperature logger. °C/°F. Continuously log up to 4 sensors located 200m+ from board. Choice of free software applications downloads for storing/using data. PCB just 45x45mm. Powered by PC. Includes 1xDS1820 sensor.
*Kit Order Code: 3145KT - **~~£19.95~~ £16.97***
*Assembled Order Code: AS3145 - **£22.97***
*Additional DS1820 Sensors - **£4.96 each***

8-Channel Ethernet Relay Card Module

Connect to your router with standard network cable. Operate the 8 relays or check the status of input from anywhere in world. Use almost any internet browser, even mobile devices. Email status reports, programmable timers, ...
*Assembled Order Code: VM201 - **£134.40***

Many items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix)

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, Rings to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
*Kit Order Code: 3140KT - **£79.95***
*Assembled Order Code: AS3140 - **£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our free Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

Infrared RC 12–Channel Relay Board

Control 12 onboard relays with included infrared remote control unit. Toggle or momentary. 15m+ indoor range. 112 x 122mm. Supply: 12Vdc/500mA
*Kit Order Code: 3142KT - **~~£64.96~~ £51.96***
*Assembled Order Code: AS3142 - **£61.96***

Temperature Monitor & Relay Controller

Computer serial port temperature monitor & relay controller. Accepts up to four Dallas DS18S20 / DS18B20 digital thermometer sensors (1 included). Four relay outputs are independent of the sensors giving flexibility to setup the linkage any way you choose. Commands for reading temperature / controlling relays are simple text strings sent using a simple terminal or coms program (e.g. HyperTerminal) or our free Windows application. Supply: 12Vdc.
*Kit Order Code: 3190KT - **~~£79.96~~ £49.96***
*Assembled Order Code: AS3190 - **£59.95***

3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone or 2-wire serial interface for microcontroller or PC communication with simple command set. Suits common anode RGB LED strips, LEDs, incandescent bulbs. 12A total max. Supply: 12Vdc. 69x56x18mm
*Kit Order Code: 8191KT - **£29.95***
*Assembled Order Code: AS8191 - **£29.95***

QUASAR electronics

velleman

cebek

Official UK Main Dealer

Stocking the full range of Cebek & Velleman Kits, Mini Kits, Modules, Instruments, Robots and more...

Card Sales & Enquiries 01279 467799

2-Ch WLAN Digital Storage Scope

Compact, portable battery powered fully featured two channel oscilloscope. Instead of a built-in screen it uses your tablet (iOS, Android™ or PC (Windows) to display the measurements. Data exchange between the tablet and the oscilloscope is via WLAN. USB lead included.

*Code: WFS210 - **£161.95** iinc VAT & Free UK Delivery*

LCD Oscilloscope Self-Assembly Kit

Build your own oscilloscope kit with LCD display. Learn how to read signals with this exciting new kit. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope has many features found on expensive units, like signal markers, frequency, dB, true RMS readouts. 64 x 128 pixel LCD display.

*Code: EDU08 - **£49.99** inc VAT & Free UK Delivery*

200 Watt Hi-Fi Amplifier, Mono or Stereo (2N3055)

Self-assembly kit based on a tried, tested and reliable design using 2N3055 transistors. Relay soft start delay circuitry. Current limiting loudspeaker protection. Easy bias adjustment. Circuit consists of two separate class AB amplifiers for a STEREO output of up to 100 Watts RMS @ 4Ω / channel or a MONO output of up to 200W @ 4Ω. Includes all board mounted components and large pre-drilled heatsink.

*Order Code 1199KT - **£69.95** inc VAT & Free UK delivery*

5” Diameter Illuminated Bench Magnifier

Professional quality magnifier ideal for PCB repair, small component assembly and general inspection applications. 22W fluorescent lamp provides excellent viewing.
5" glass lens.
1.5X magnification.
Flexible 32" reach arm.
Supplied with table clamp.
230Vac UK mains. Weight: ~3Kg.

*Order Code 700.015 - **£42.95** inc VAT & Free UK delivery*

PC-Scope 1 Channel 32MS/s With Adapter

0Hz to 12MHz digital storage oscilloscope, using a computer and its monitor to display waveforms. All standard oscilloscope functions are available in the free Windows program supplied. Its operation is just like a normal oscilloscope. Connection is through the computer's parallel port, the scope is completely optically isolated from the computer port. Supplied with one insulated probe x1/x10.

*Code: PCS100A - **£124.91** inc VAT & Free UK Delivery*

2-Channel PC USB Digital Storage Oscilloscope

Measurement up to 2 x 60MHz!
USB
Pc-Lab2000SE
OSCILLOSCOPE
TRANSIENT RECORDER
SPECTRUM ANALYSER

Uses the power of your PC to visualize electrical signals. High sensitivity display resolution (down to 0.15mV), high bandwidth and sampling frequency up to 1GHz. Easy setup USB connection. No external power required! In the field measurements using a laptop have never been this easy. Stylish vertical space saving design. Powerful free Windows software.

*Code: PCSU1000 - **£246.00** inc VAT & Free UK Delivery*

Four Legged AllBot Kit

From the AllBot modular robot system with Arduino® compatible robot shields. Build and enhance the robot, learn how to program, use the app and have fun! Includes all necessary plastic parts, 4 x 9G servo motors, a servo motor connector shield (VRSSM), a battery shield (VRBS1).

*Code: VR408 - **£104.34** inc VAT & Free UK delivery*

PC USB Oscilloscope & Function Generator

Complete USB-powered Lab-in-a-Box! Free feature-packed software for two channel oscilloscope, spectrum analyser, recorder, function generator and bode plotter. With the generator, you can create your own waveforms using the integrated signal wave editor. For automated measurements, it is even possible to generate wave sequences, using file or computer RS232 input. 60MHz scope probe included

*Code: PCSGU250 - **£135.60** inc VAT & Free UK Delivery*

No.1 FOR KITS

www.QuasarElectronics.co.uk

Secure Online Ordering Facilities ● Full Product Listing, Descriptions & Images ● Kit Documentation & Software Downloads

PRICE FROZEN

EVERYDAY PRACTICAL ELECTRONICS

SUBSCRIPTION PRICES FROZEN FOR 2017

UK readers you can SAVE 81p on every issue of *EPE*

How would you like to pay £3.59 instead of £4.40 for your copy of *EPE*?

Well you can – just take out a one year subscription and save 81p an issue, or £9.80 over the year. You can even save £1.08 an issue if you subscribe for two years – a total saving of £26.10

Overseas rates also represent exceptional value

You also:

- **Avoid any cover price increase for the duration of your subscription**
- **Get your magazine delivered to your door each month**
- **Ensure your copy, even if the newsagents sell out**

Order by phone, or fax with a credit card, or by post with a cheque or postal order, or buy online from www.epemag.com (go to the Online Shop).

EVERYDAY PRACTICAL ELECTRONICS

SUBSCRIPTION PRICES

Subscriptions for delivery direct to any address in the UK: 6 months £23.50, 12 months £43.00, two years £79.50; Europe Airmail: 6 months £28.00, 12 months £52.00, 24 months £99.00; Rest Of The World Airmail: 6 months £37.00, 12 months £70.00, 24 months £135.00.

Cheques or bank drafts (in **£ sterling only**) payable to *Everyday Practical Electronics* and sent to EPE Subs. Dept., Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU. Tel: 01202 880299. Fax: 01202 843233. **Email:** subs@wimborne.co.uk. Also via the **Web** at: **www.epemag.com**.

Subscriptions start with the next available issue. We accept MasterCard, Maestro or Visa. (For past issues see the Back Issues page.)

ONLINE SUBSCRIPTIONS

Online subscriptions, for reading the magazine via the Internet, £19.99 for one year, visit **www.epemag.com** for more details.

SUBSCRIPTION ORDER FORM

☐ 6 Months: UK £23.50, Europe £28.00 (Airmail), Rest Of The World £37.00 (Airmail)
☐ 1 Year: UK £43.00, Europe £52.00 (Airmail), Rest Of The World £70.00 (Airmail)
☐ 2 Years: UK £79.50, Europe £99.00 (Airmail), Rest Of The World £135.00 (Airmail)

To: Everyday Practical Electronics,
Wimborne Publishing Ltd., 113 Lynwood Drive, Merley,
Wimborne, Dorset BH21 1UU
Tel: 01202 880299 Fax: 01202 843233
E-mail: subs@epemag.wimborne.co.uk

I enclose payment of £ .... (cheque/PO in £ sterling only), payable to *Everyday Practical Electronics*

☐ Please charge my Visa/Mastercard/Maestro

My card number is: ....
Please print clearly, and check that you have the number correct

Signature ....

Card Security Code .... Valid From Date........................
(The last 3 digits on or just under the signature strip)

Card Ex. Date ....

Name ....

Address ....

Post code .... Tel. ....

Subscriptions can only start with the next available issue.

MasterCard VISA

EXCLUSIVE OFFER

Microchip and EPE have teamed up to bring you this AMAZING offer

USUAL PRICE
£68.64
(Inc VAT)
(model DV164131)

MPLAB® IDE
Includes: MPLAB IDE, Documentation, Quick Reference Cards, Language Tool Demos, User Guides and Tutorials
MICROCHIP
PICkit 3
POWER
ACTIVE
STATUS

The PICkit 3 allows debugging and programming of PIC and dsPIC Flash microcontrollers using the powerful graphical user interface of the MPLAB Integrated Development Environment (IDE). This kit includes the 44-pin demo board with a PIC18F45K20 microcontroller and a USB cable. Microchip's FREE MPLAB IDE software and the FREE Edition of the C Compiler provide a complete code development environment, and are available via free download from microchip.com

Spend over £125 on any of EPE's products, including subscriptions, and receive a PICkit 3 worth £68.64 for FREE

This offer is available to UK & overseas customers; however, for orders in Europe & ROW the following amounts will be added to cover postage:
£4.05 Europe: £5.10 ROW

Only 30 left, so hurry while stocks last!

Go to www.epemag.com to check availability

(Please note: subscriptions purchased with this offer cannot be cancelled before they expire; also, goods purchased with this offer can only be returned for exchange)

OFFER ONLY VALID WHILE STOCKS LAST – DON'T MISS OUT!! JUST CALL 01202 880299 OR VISIT OUR SECURE ONLINE SHOP AT: www.epemag.com

MICROCHIP
www.microchipDIRECT.com

EPE EVERYDAY PRACTICAL ELECTRONICS

Sales: 0191 251 4363 www.TheElectronicsShop.co.uk

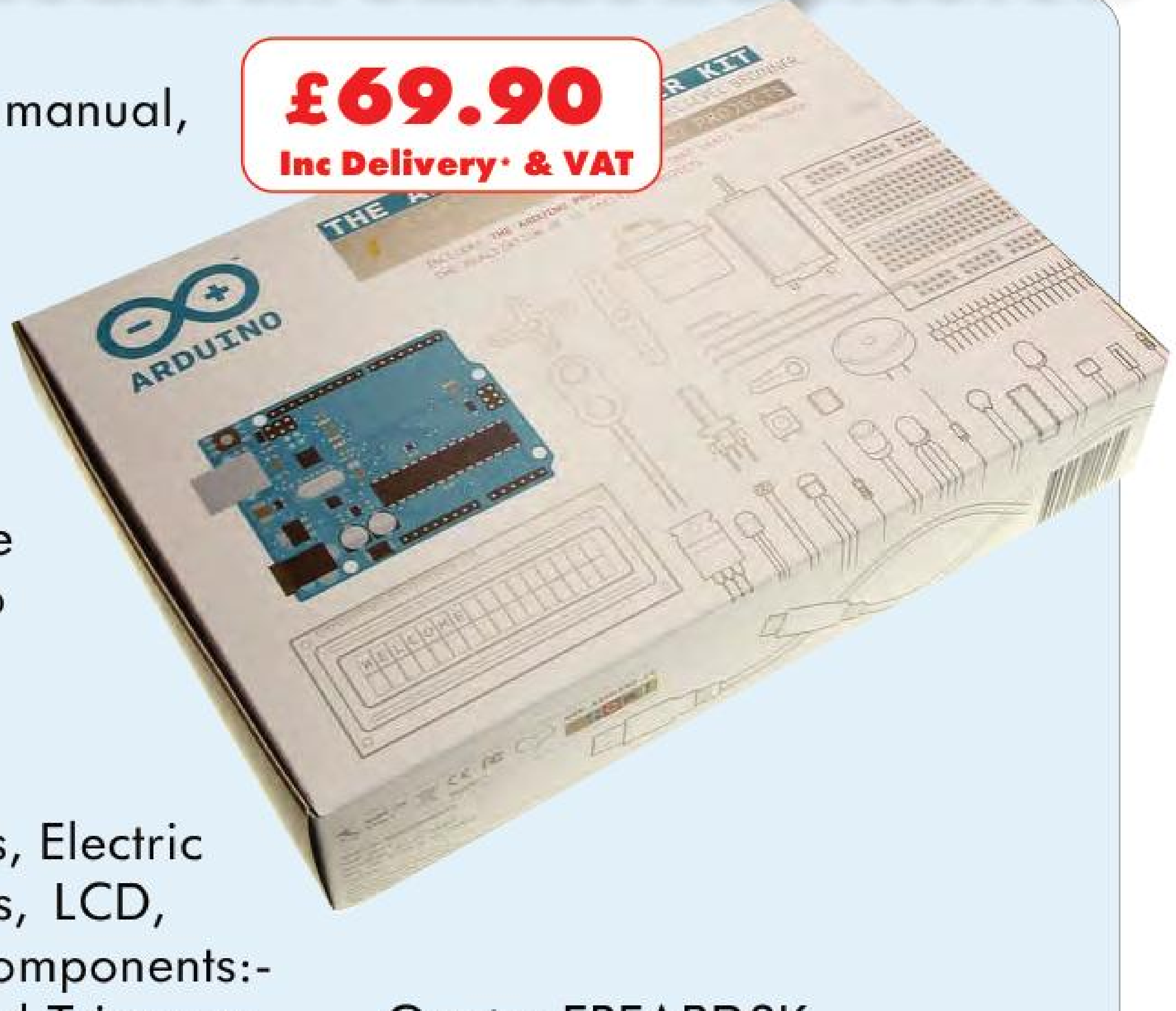
Arduino Starter Kit

Genuine Arduino Starter kit which comprises of a 170 page instruction manual, Arduino UNO Board, Breadboard, components & more.

The kit walks you through the Arduino programming and basic electronics in a hands on way. You will be able to build 15 projects using the components supplied. They allow you to control the physical world through different kinds of sensors and actuators. Once you have mastered this knowledge, you will have the ability and circuits to create something beautiful, and make someone smile with what you invent. So build, hack and share!

This Starter kit is supplied with a Wood base, USB & Interconnect leads, Electric motor, Piezo sounder, Movement and Temperature sensors, Switches, LCD, Breadboard & Servo motor. The kit also includes over 100 electronic components:- Diodes, Transistors, Capacitors, h-Bridge, Resistors, LED's, Switches and Trimmers. Quote: EPEARDSK

£69.90
Inc Delivery* & VAT



Offical Arduino Dealer

Genuine Arduino UNO R3 from £18.98+p&p

Wide range of Boards,Shields & Accessories

HPG1 Function Generator

A complete pocket function generator. Now you can take test signals on the move, 3 waveforms can be selected. Set the output voltage or frequency and select signal waveform using the on the screen menu. A powerful sweep function is also included.

* Frequency range: 1Hz to 1.000.000Hz
* Frequency steps: 1Hz, 10Hz, 100Hz, 1kHz and 10kHz
* Sine, square and triangle wave forms
* Runs on NiMH rechargeable battery pack (includeed)
* BNC Lead and Charger Included.
Quote: EPEHPG

£91.19
Inc Delivery* & VAT

HPS140i Oscilloscope

The HPS140i Oscilloscope packs al lot of power in a tiny box. Now you can really take a powerful oscilloscope everywhere. These features make the HPS140 indispensable to the professional user, service centres and even to the hobbyist. Supplied with a probe.

* 40Mhz real time sample rate
* Full auto range option
* Hold & store function
* Operates up to 6 hours on one charge
* Scope Lead and Charger Supplied

Quote: EPEHPS

£99.60
Inc Delivery* & VAT

2.4GHz Frequency Counter

0.01Hz to 2.4GHz
8 Digit LED Display
Gate Time: 100ms to 10s
2 Channel Operating mode
Power Supply: 110-220Vac 5W
Quote: EPE24G

£81.00
Inc Delivery* & VAT

30V 5A Programmable PSU

Dual LED (Voltage & Current) Displays
Course & Fine Voltage /Current Adjustment
Volatge or Current Limiting.
* 5 Memories
* PC Link via USB or RS232
*Output:
0-30Vdc
0-5A

Quote: EPEPSU

£99.90
Inc Delivery* & VAT

Build your own Oscilloscope

A new self assembly kit, ideal for education and way to visualise signals. Features: Markers, Frequency, dB, True RMS readouts
Timebase range:
10μs-500ms/division (15 steps)
Input sensitvity:
100mV-5V/division (6 steps)
Max Input voltage: 30Vpp
Max Sample Rate:
1ms/s repetitive signal,
100ks/s real time signal
Dim: 80 x 115 x 40mm

Quote: EPESCOPE

£49.99
Inc Delivery* & VAT

www.esr.co.uk

Tel: 0191 2514363
Fax: 0191 2522296
sales@esr.co.uk

ESR Electronic Components Ltd
Station Road,
Cullercoats, Tyne &
Wear. NE30 4PQ

Prices **INCLUDE** Delivery* & VAT.
*Delivery to any UK Mainland address, please call for delivery options for Highland & Island, Northern Ireland, Ireland, Isle of Man, Isle of Wight & Channel Islands

03/17

VOL. 46 No. 04 APRIL 2017

Editorial Offices:
EVERYDAY PRACTICAL ELECTRONICS
EDITORIAL Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
Phone: 01202 880299. **Fax:** 01202 843233.
Email: fay.kearn@wimborne.co.uk
Website: www.epemag.com
See notes on **Readers' Technical Enquiries** below – we regret technical enquiries cannot be answered over the telephone.

Advertisement Offices:
Everyday Practical Electronics Advertisements
113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
Phone: 01202 880299 **Fax:** 01202 843233
Email: stewart.kearn@wimborne.co.uk

Editor:	MATT PULZER
Subscriptions:	MARILYN GOLDBERG
General Manager:	FAY KEARN
Graphic Design:	RYAN HAWKINS
Editorial/Admin:	01202 880299
Advertising and Business Manager:	STEWART KEARN 01202 880299
On-line Editor:	ALAN WINSTANLEY
Publisher:	MIKE KENWARD

READERS' TECHNICAL ENQUIRIES
Email: fay.kearn@wimborne.co.uk
We are unable to offer any advice on the use, purchase, repair or modification of commercial equipment or the incorporation or modification of designs published in the magazine. We regret that we cannot provide data or answer queries on articles or projects that are more than five years' old. Letters requiring a personal reply must be accompanied by a stamped self-addressed envelope or a self-addressed envelope and international reply coupons. We are not able to answer technical queries on the phone.

PROJECTS AND CIRCUITS
All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in EPE employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD adaptor.

COMPONENT SUPPLIES
We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers.

We advise readers to check that all parts are still available before commencing any project in a back-dated issue.

ADVERTISEMENTS
Although the proprietors and staff of EVERYDAY PRACTICAL ELECTRONICS take reasonable precautions to protect the interests of readers by ensuring as far as practicable that advertisements are bona fide, the magazine and its publishers cannot give any undertakings in respect of statements or claims made by advertisers, whether these advertisements are printed as part of the magazine, or in inserts.

The Publishers regret that under no circumstances will the magazine accept liability for non-receipt of goods ordered, or for late delivery, or for faults in manufacture.

TRANSMITTERS/BUGS/TELEPHONE EQUIPMENT
We advise readers that certain items of radio transmitting and telephone equipment which may be advertised in our pages cannot be legally used in the UK. Readers should check the law before buying any transmitting or telephone equipment, as a fine, confiscation of equipment and/or imprisonment can result from illegal use or ownership. The laws vary from country to country; readers should check local laws.

What will you do with Micromite?

This month, we come to the end of our brief but thorough introduction to the Micromite, a small, but impressive microcontroller that combines the raw processing power of 32-bit PIC technology with the flexibility and ease of use of the BASIC language. However, it's by no means the last that we'll hear from this Australian marvel in *EPE*. Next month, we will add a bespoke touch-screen that greatly increases the device's ability to control, automate and sense the world of electronics and beyond. Further on in the year we will have other exciting projects and 'how to' articles' that involve the Micromite, and so my advice is not only to read and enjoy this month's article, but also consider buying this wonderful (and very cheap) device. Experiment, build and have fun with it! And as always, drop us a line and let us know what you have achieved.

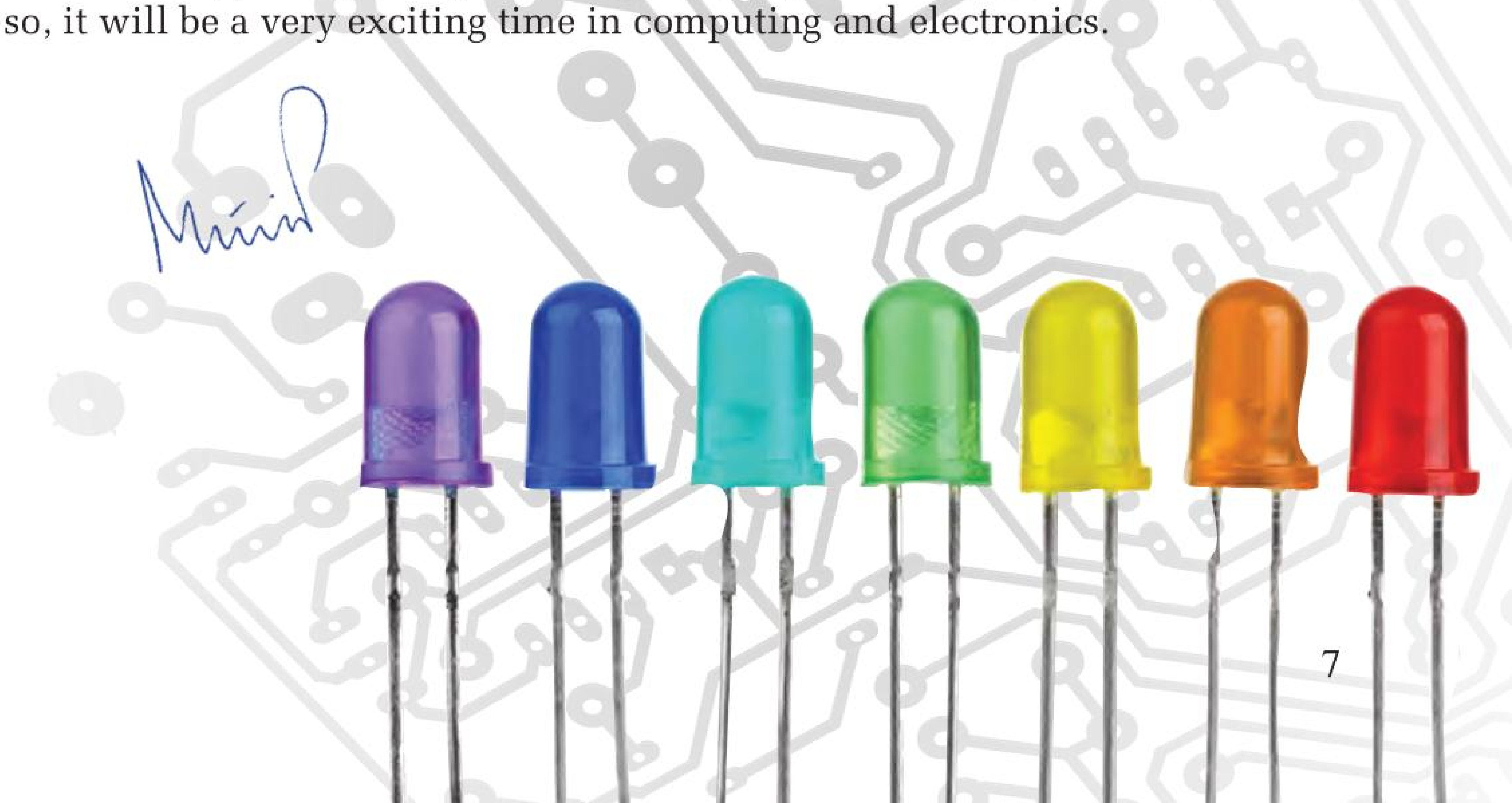
Jam tomorrow

Power – computer processing and electrical, are the two great commodities of the modern era. So it comes as no surprise that two of the biggest engineering-physics projects in the world are the search for near-free power and spectacular computing power – I refer of course to fusion reactors and quantum computing. What do these two quests have in common? They always seem to be just around the corner, but that corner never quite gets reached. Fusion power – where the only fuel you need is a trivial amount of hydrogen (ie, water) – has been actively researched since the 1950s, and while progress has undoubtedly been made, the dream of 'electricity too cheap to meter' remains decades away.

But what of the other great pursuit, what has happened in the world of quantum computing, which proponents claim will revolutionise industry, commerce and science? Well, apparently, it's all happening on my doorstep – literally! Just up the road from where I live (in Brighton) at the University of Sussex, an international team has unveiled the first practical blueprint for how to build a quantum computer. The next stage is the construction of a prototype quantum computer, based on this design at the University. The machine is expected to fill a large building, consisting of sophisticated vacuum apparatus featuring integrated quantum computing silicon microchips that hold individual charged atoms (ions) using electric fields.

Professor Winfried Hensinger, head of the Ion Quantum Technology Group at the University of Sussex, who has been leading this research, said: 'For many years, people said that it was completely impossible to construct an actual quantum computer. With our work we have not only shown that it can be done but now we are delivering a nuts and bolts construction plan to build an actual large-scale machine.' Hensiger discusses his work here: **https://youtu.be/naqHy5MAYXw**

Who knows, perhaps for quantum computing tomorrow is about to arrive. If so, it will be a very exciting time in computing and electronics.



NEWS

A roundup of the latest Everyday News from the world of electronics

RIP Cyanogen, hello simple DIY solar power – *report by Barry Fox*

Cyanogen, the open-source tweaked version of Google's Android operating system is no more.

Cyanogen was adopted by WileyFox, the British company that sells high-spec 'Swift' smartphones online, at lower cost than similarly specified big-name phones. But Google has been tweaking 'pure' Android and the adoption of Cyanogen slowed, and so development has faltered. This has left WileyFox with the problem of how to provide past, present and future owners of Swift phones with software updates.

CEO Michael Coombes recently revealed his plan. Over the coming months, WileyFox will provide over-the-air updates which convert all its phones to 'pure' Android Version 7, nick-named 'Nougat'. The name Cyanogen will then disappear from WileyFox boot-up screens.

Two-tray option saved

One very important feature of the WileyFox phones will, however, remain; they will continue to have either two SIM card trays or one SIM tray and another tray, which accepts either a SIM or Micro SD card. Both trays are 'unlocked' so will take any network SIM. This gives the owner an instant choice of networks, for instance where reception is better for Vodaphone than EE, or when a data plan such as Three's 123 is more appealing than O2's Pay as You Go; or a SIM bought on a foreign trip can be used abroad without preventing the phone from receiving speech calls and texts to the UK number.

Careful and creative SIM juggling can save the user considerable costs – which is why UK networks have always rejected the idea of providing customers with subsidised dual-SIM phones. But WileyFox is now hoping to change the networks' mindset.

Google
12:30
Sat, August 1
Google
Play
Themes
Play Store

WileyFox Cyanogen phones such as the Swift or Storm are migrating to Android 7 (Nougat)

Says Michael Coombes: 'We can, if necessary, electronically lock both the SIM trays to the same network so that users can have two SIMs with different numbers or tariffs. Or we can even physically glue one tray closed, or cover it with tape'.

This could create a whole new world of challenges for hackers – how to re-activate a de-activated second SIM tray.

A brief guide to DIY solar power

For decades, homes in Japan have had solar-powered water heaters on their roofs – water for bathing is circulated through panel pipes to a hot storage tank. Now, solar-electric panels are rapidly replacing those water systems.

In the not-so-sunny UK, homes often have panels that earn some electricity bill credit by feeding power into the grid. Solar farms – fields of panels – are popping up, especially in the south of England.

In sunny Spain you will see satellite TV dishes on most rural roofs, but very few solar systems. An ex-pat explains: 'The only reason is because the power companies lobby the government to keep the price of the panels prohibitive. Which is madness in a country where daily sunshine is taken for granted'.

So why, when people in Spain are buying UK satellite systems by mail order, for DIY fitting, is the same thing not happening with solar panels? – because there is a widespread lack of basic DIY solar knowledge.

Here then, are a few basics, learned the hard way over several years of practical trial-and-error experimenting with available technology.

Top tips

Feeding 230V AC into the grid is not a DIY project. But storing 12V DC with batteries, and then using the DC to run 12V caravan or boat equipment is affordable, safe and easy. So is up-converting 12V DC to 230V AC (isolated from the grid).

Don't waste money on small panels; buy at least one 20W, 48cm panel or larger, and ideally gang several in parallel. Each panel will chuck out around 20V, which will fry batteries on a sunny day when the current steps up. So a PWM charge controller is essential. The bundled price for panel and controller can now be under £50.

An inverter, which handles a few hundred watts of 12V DC-to-230V AC can now be had for under £30. This is more than enough juice to run a modern TV, PC, eco-lamp or LED light. Often, the inverter will now include a 5V USB socket for charging phones.

A brief guide to DIY solar power *continued*

The charge controller and inverter will usually not be waterproof, so it needs weather protection.

Don’t mess with lithium batteries unless you really know what you are doing; they are expensive and likely to explode if the charge rate is not just right. NiCad batteries lose their ability to hold a charge. So stick with tried and tested, good old-fashioned lead-acid technology. Sealed gel cells are compact, but cost more for less capacity and (in my experience) are more likely to fail.

Unless size is an issue, go for warhorse car batteries, which are designed for rough treatment. It’s hard to think of rougher treatment than sitting next to a hot petrol engine and delivering huge currents to a starter motor in the freezing cold. Several lead acids can be ganged in parallel to increase storage capacity.

Often, car owners have to change their battery in the winter because cold-starting gets sluggish when the engine oil thickens. The discarded battery may still be good enough for solar storage where there is no need for sudden current surges, and the cells are being continually topped up during the day.

So, if a friend needs to replace a car battery, ask to keep the old one. Or ask a friendly garage if they have some serviceable throw-outs they will sell for a few quid. But check each battery separately for charge-holding before parallel-ganging, because one bad battery will drag down the rest.

…and finally

Last, but not least, if you really get the solar power bug and want to move on from plain vanilla panels and lead-acid batteries, *EPE* often carries advanced solar power projects that will enable you to safely and economically use modern battery technology such as lithium-ion, lithium-polymer or $LiFePO_4$ (see this month and February/March 2017).

MeArm Pi – Raspberry-Pi-controlled robot arm

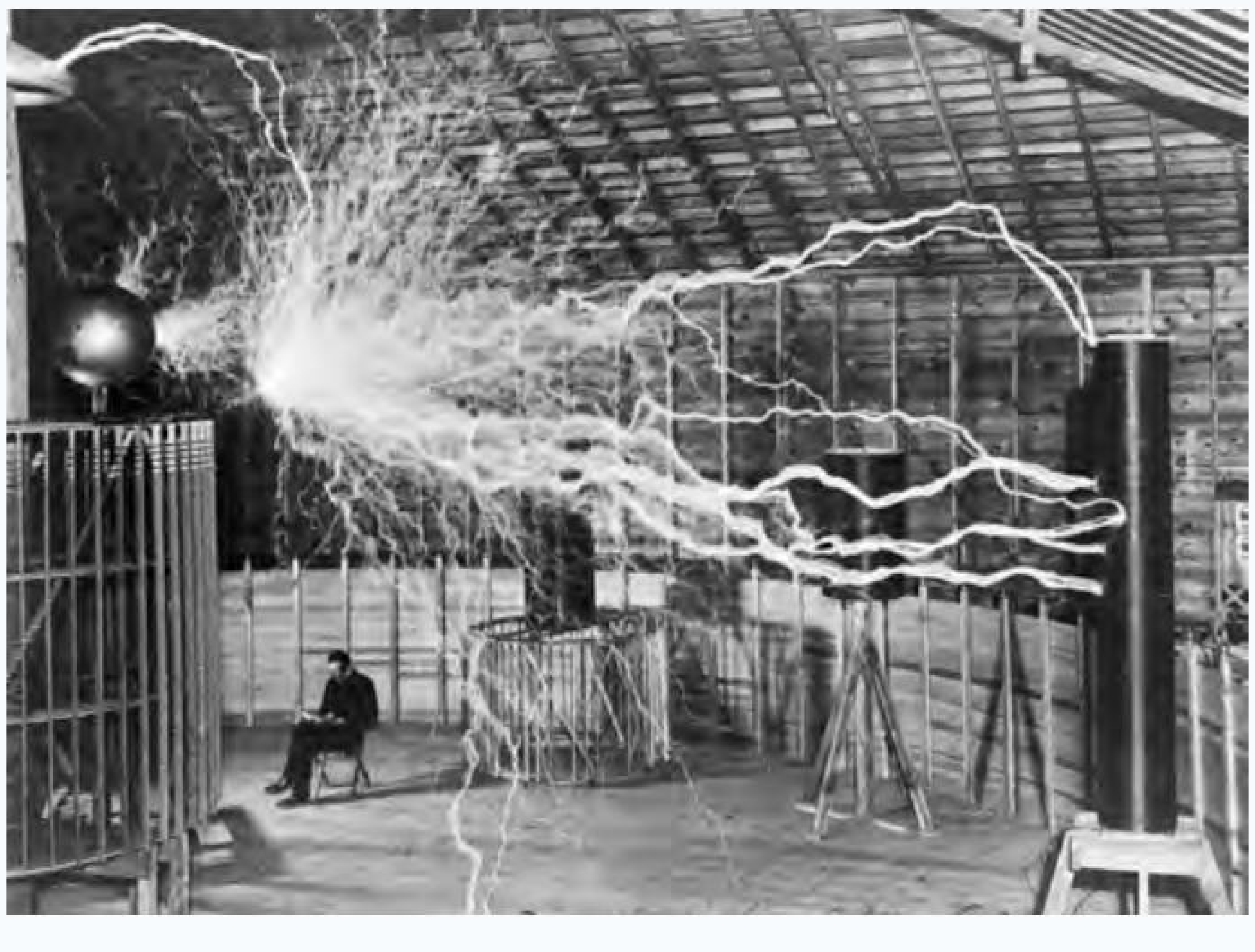
The MeArm Pi Kit is a build-it-yourself robot arm that’s controlled by a Raspberry Pi. It includes a standard Pi HAT that attaches to your Raspberry Pi and has a couple of on-board joysticks to control it. Because it’s connected to the Pi you can program it through any of the various programming languages that already run on the Pi. There’s also free software available which lets you program it through a web interface using drag and drop programming environments like Scratch and Blockly, or with Python and Javascript for the more experienced.

Further details from Mime Industries at: **https://mime.co.uk**

Electricity: The spark of life

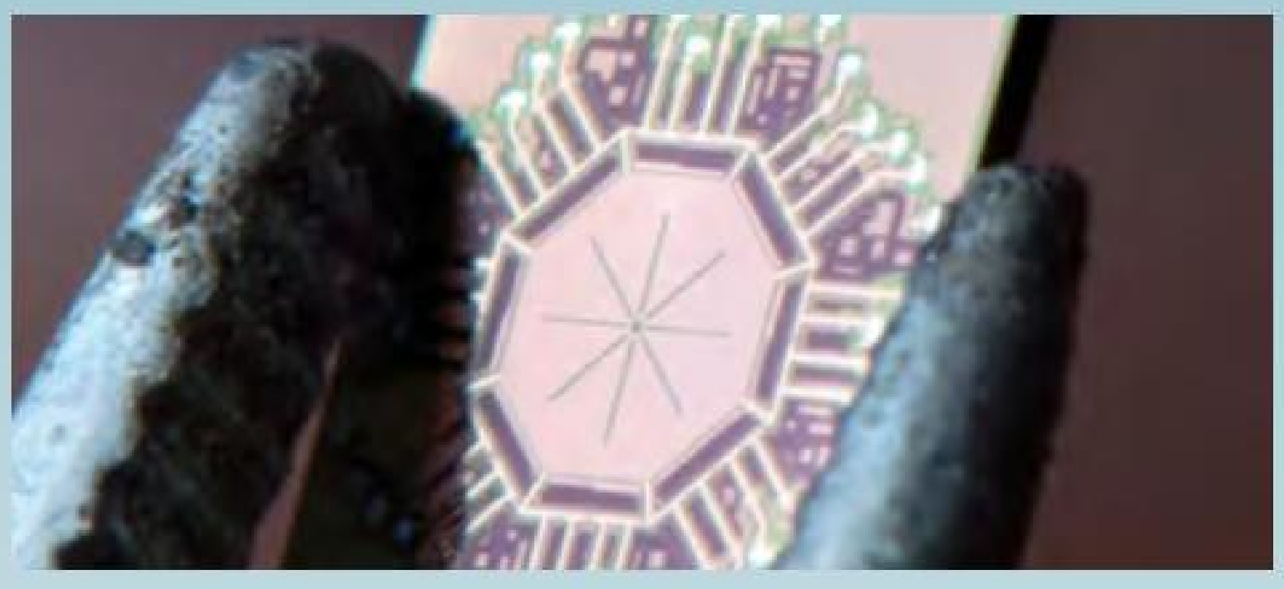
If you are in London before 25 June then do consider visiting the Wellcome Collection on the Euston Road for its imaginative exhibition on electricity. As the guide explains, ‘From the structure of the atom to the function of our brains, an electric charge is hidden within every object on earth. *Electricity: The spark of life* will trace the story of mankind’s quest to understand, unlock and master the power of electricity.’

For further details: **https://wellcomecollection.org/electricity**



Nikola Tesla in his lab, 1901 (Wellcome library, London)

Breakthrough radiator



A doctor waves a hand-held scanner over your body and gets high-resolution images of your internal organs and tissues. Using the same device, the physician then sends gigabytes of data instantly to a remote server and just as rapidly receives information to make a diagnosis. Researchers at the University of California, Irvine (UCI) have created a silicon-based component that could make this possible.

Known as a ‘radiator,’ the tiny gadget emits millimetre-wave signals (110 to 300GHz). Waves of this frequency easily penetrate solid surfaces and provide extremely sharp resolution, enabling new, more effective methods of biomedical and security scanning and imaging. The device can also perform a key role in point-to-point wireless communication.

The UCI invention performs three crucial functions: it combines power from multiple amplifiers; it modulates that signal to a desired frequency setting; and it radiates it out in waves that are used to see, sense or communicate. Plus, by making a single device that provides a multitude of operations, all the interstage, inefficient systems found in other radiators have been eliminated.

The device is an octagonal semiconductor chip with a unique cavity structure that allows for the emission of circularly polarised radiation. Most transmitters generate linearly polarised signals, which can get ‘lost’ when antennas and receivers are out of alignment. Emissions from one of the UCI radiators, if you could see them, would appear as tiny spinning tornados. Beams of this shape are particularly effective at penetrating solid objects and providing detailed pictures of what’s inside.

The invention will be particularly beneficial in biomedical applications, but the new radiator can do a lot more than facilitate scanning and imaging. It could be the key that unlocks millimetre-wave transmission as part of the fifth-generation wireless standard now in development. In addition, the tiny-yet-powerful device can be embedded virtually anywhere, supporting the Internet of things, which relies heavily on machines, buildings and other infrastructure being equipped with sensors and antennae.

microchip
DIRECT

microchipDIRECT
Memory Programming
We Can Now Program Memory Devices
BUY DIRECT
at
microchipDIRECT.com

microchipDIRECT offers access to the world's largest inventory of Microchip products and the most comprehensive online resource for pricing and support directly from Microchip Technology. We invite you as a valued Microchip customer to experience our service 24 hours a day, 7 days per week.

Visit www.microchipDIRECT.com and enjoy the confidence and convenience of buying from microchipDIRECT and take advantage of the following features:

- Direct stock from factory
- Direct customer service
- Secure ordering
- Volume pricing
- Credit lines
- Long-term orders and scheduling
- Programming and value add services
- Ability to adjust open orders
- Ship to your sites globally
- Online order status and notifications

microchip
DIRECT
www.microchipdirect.com

MICROCHIP

www.microchipDIRECT.com

The Microchip name and logo, the Microchip logo are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries. All other trademarks are the property of their registered owners.
© 2015 Microchip Technology Inc. All rights reserved. DS40001752B. MEC2010Eng04/15

TechnoTalk

Zero value – but not valueless!

Mark Nelson

Have you encountered zero-ohm resistors yet? If they strike you as the daftest thing yet, this article may change your mind. And what about electric petrol? It's the latest innovation and might save Britain fortunes on imported fuel.

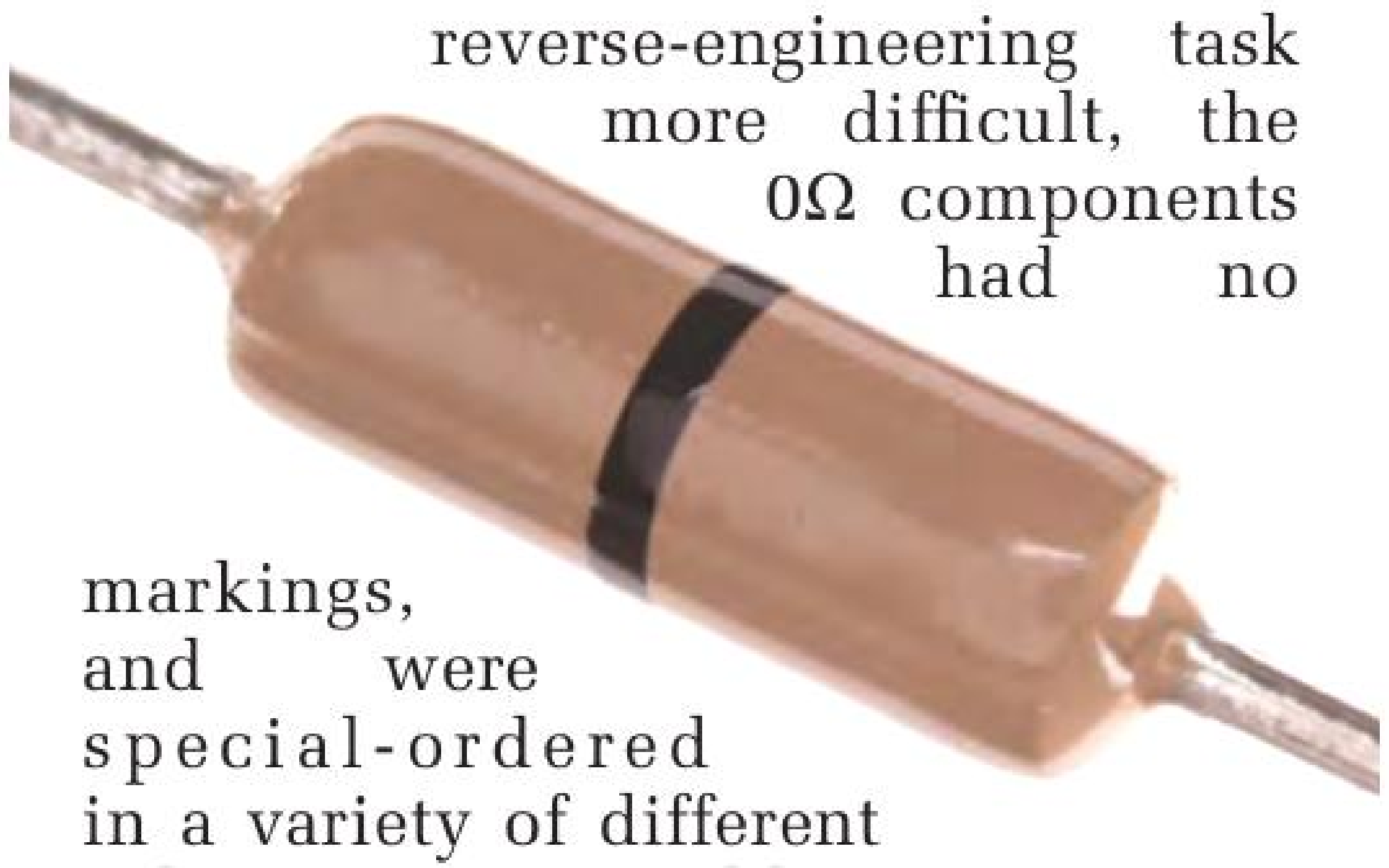
'RETARDED DEVELOPMENT' IS MY middle name, so it may come as no surprise that it was only last year that I first encountered zero-ohm resistors. If they have not yet appeared on your particular planet, let me assure you that they do actually exist and have a very real function in everyday practical electronickery. Just enter the term into eBay and you will find the top two hits show the two main types of this device, one looking like a normal 0.25W resistor and the other in the form of a standard surface-mount 'chip' resistor.

No joke

First off, these little critters are not an April Fool's joke and have been used for decades, hidden in plain sight and looking like other resistors. Usually, they are employed as an alternative to a wire link or 'strap' and being of a consistent size, they can be placed by robot assembly machines. They have many advantages, as the Web reveals. Often, they are used on single-layer boards for connections that cannot be routed on copper due to density. In other cases, 0Ω resistors are used as factory switches, when the same PCB board can be equipped in several variants, and particular connections must exist in each variant. A simple way of making 115V and 230V versions of the same power supply board could be to place a 0Ω resistor either at one place or another to route the line voltage to different windings on the transformer. The 0Ω resistors could be connected to different pins on, for example, a microcontroller, to pull pins high or low. When it reads which pins are pulled high and low, it sets up different parameters in the software. Or you could provide an optional filter circuit, with a 0Ω resistor for bypassing the filter, sending the signal another way. This is much cheaper than making separate, differing PCBs.

Deeply devious

Another use is for a test point. You can remove the zero-ohm resistor and apply a signal generator, then replace it. But they also have more strategic uses. On the *EE Times* 'Planet Analog' website, Bill Schweber recalls a cunning plan. It was standard practice at some firms to put these devices at various places on the PCBs to confuse anyone trying to reverse-engineer the design from a physical unit. In fact, to make this reverse-engineering task more difficult, the 0Ω components had no markings, and were special-ordered in a variety of different colours, so it would appear that they were different devices.



Electric petrol

They used to call crude oil 'black gold', but the talk now is of 'white petroleum' alias 'electric petrol'. Yes, this is another 'fossil' fuel that you dig up from the ground and as with crude oil, its resources are intrinsically finite. But electric petrol is renewable, if you stretch the point. Well, rechargeable at least, but I had better stop talking in riddles.

In fact, we are talking about lithium, that peculiar metal that is as soft as cheese, lighter than any other metal and also the least dense solid element. For many years, most people would give you a puzzled look if you mentioned its name and folk would recognise it only as a 'chemical cosh' used for treating bipolar illness, schizoaffective disorders and major depression. Then along came mobile phones and the need for smaller batteries that could hold their charge longer than a single day. In 1991, the Sony Corporation released the first commercial lithium-ion battery in partnership with Asahi Kasei. 20 years later, lithium-ion batteries managed to account for two thirds of all portable rechargeable battery sales in Japan.

Time to hit the road

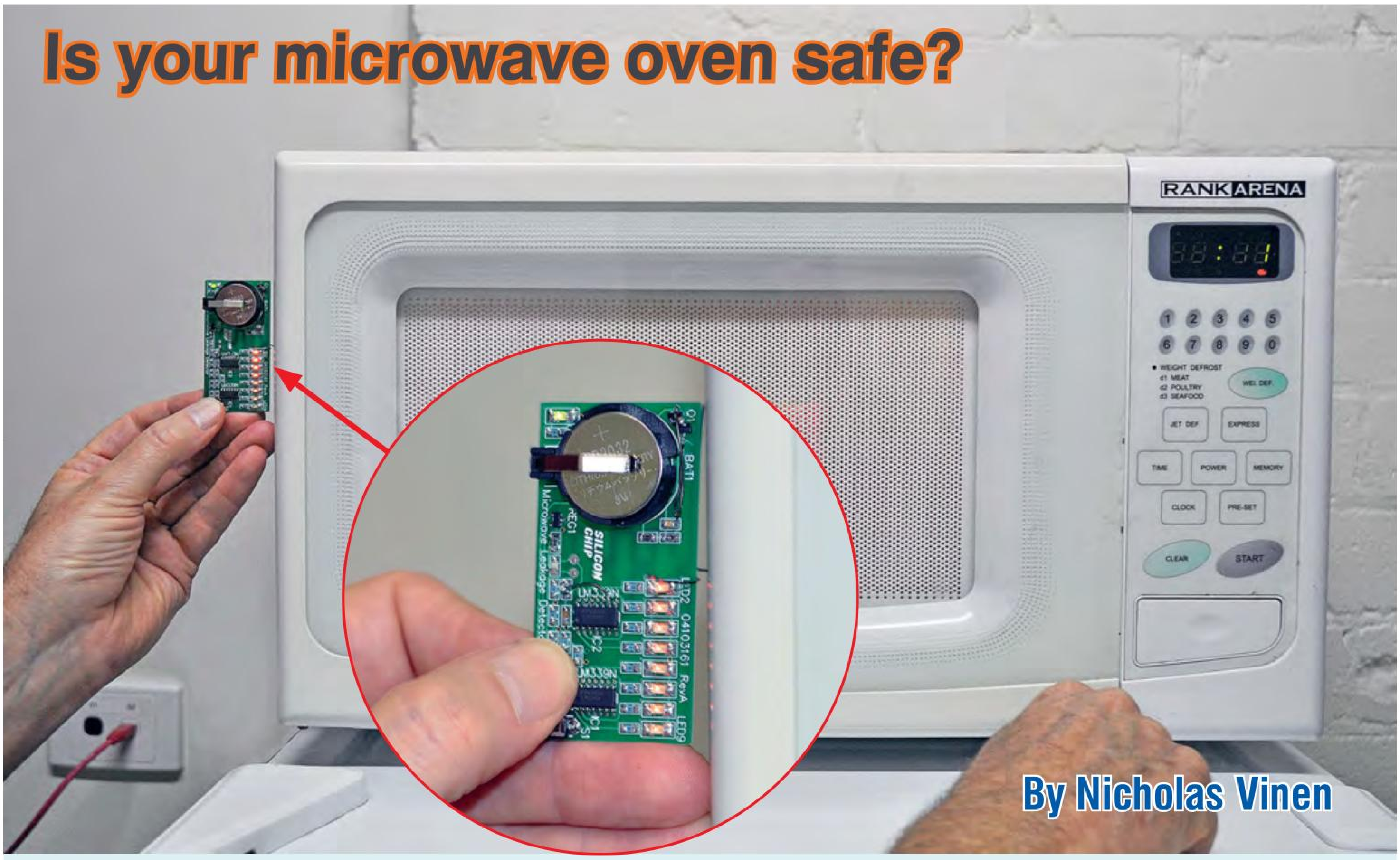
So what's the attraction of lithium-based batteries? Basically, the low atomic mass of lithium endows it with extremely high charge-to-weight and power-to-weight ratios. Up to now, most of these batteries have been used in consumer electronics, but now their use is increasing rapidly in cars, motorcycles, heavy vehicles and off-road equipment. Proponents cite up to 80 per cent weight saving, an ability to charge and discharge at high currents, recharging times of five minutes and a minimum of five years' service life, rising to ten years depending on use. Car giant Volkswagen is quoted as wanting up to 25 per cent of its sales to be electric vehicles by 2025. The switch towards electric cars across the world is expected to cause the market for lithium to quadruple to £70 billion by 2020, assuring strategic importance to the metal.

Currently, most lithium is produced in South America, Australia and China, but in January a British company by the name of 'Cornish Lithium' announced plans to extract the metal at locations across Cornwall where it is known to exist. Chief executive Jeremy Wrathall stated: 'We believe the potential benefits of developing a lithium industry in Cornwall will be significant for the county and for the UK as a whole. This is a hugely exciting opportunity to put Cornwall back on the map as a mining centre, as well as develop a new industry in the UK.'

Eco-friendly

Mining lithium comes at a cost, although it is considered less hazardous than other kinds of mineral extraction. At some locations it is carried to the surface in the leachate (liquid) of geothermal wells, and as long ago as 1864 high levels of lithium were detected in water flowing into Cornwall's now abandoned tin mines. This geothermal energy raises the possibility of harvesting environment-friendly power as a by-product of the lithium extraction process, tilting the nett environmental impacts potentially positive. Let's hope the availability of home-harvested lithium brings down the price of car batteries to make electric cars as cheap as chips. We will see.

Is your microwave oven safe?



By Nicholas Vinen

... don't get zapped – test it with our

Microwave Leakage Detector!

Just because your microwave oven still looks shiny and new does not mean it is safe. It could be leaking lots of microwave energy, potentially putting you at risk of being zapped. Now you can easily test it with our tiny *Microwave Leakage Tester*. As a bonus, it will also test Wi-Fi access point activity.

DO YOU SLAM the door of your microwave oven after you've used it? Of course you do! Everyone does! That repeated slamming can damage the integrity of the mesh inside the glass door, so that as time goes by the shielding becomes less effective, allowing some microwave radiation to leak out around the edges.

In particularly bad cases, enough RF could leak out to cause injury. Since RF energy is invisible, the question becomes how do you know whether your microwave oven is still safe?

Basically, you need to run our *Microwave Leakage Detector* around the edges of the door while the oven is operating, to check that it's safe. The level of microwave leakage (field strength) is indicated with an 8-LED bargraph. As the microwave oven is operating (and the turntable is rotating), you will see a surprising variation in leakage as you run the *Microwave Leakage Detector* around the door edges.

The detector is powered by a lithium button cell with low drain and no standby current. This unit can also be used to check whether 2.4GHz transmitters, such as those in Wi-Fi routers, are active. If the Detector is held up to the base station antenna, its LEDs will flicker in response to network activity and the number of LEDs lit will indicate the transmission power level.

Operation

A *Microwave Leakage Detector* is a type of AM radio receiver tuned for signals around 2.5GHz, with an indicator of the RF field strength. Because we're mainly concerned with indicating the presence of fields and whether they are above a certain hazard power threshold, we don't need a very complex circuit. Issues such as distortion, bandwidth, linearity and so on are not important.

The basic principle of this detector is based on an article published in the

July 1979 issue of *Electronics Today International* (*ETI*). A dipole antenna is formed from two collinear tracks on the PCB, with each track's length being one-quarter of the wavelength for 2.5GHz signals (12cm). A 'hot-carrier' Schottky barrier detector diode is used to detect the signal and its output is filtered by a 220pF ceramic capacitor.

Two low-value inductors, comprising zig-zag tracks on the PCB, connect the detector diode to the filter capacitor. These prevent the capacitor's low impedance from excessively loading the dipole and also enhance the filtering operation of the capacitor at microwave frequencies.

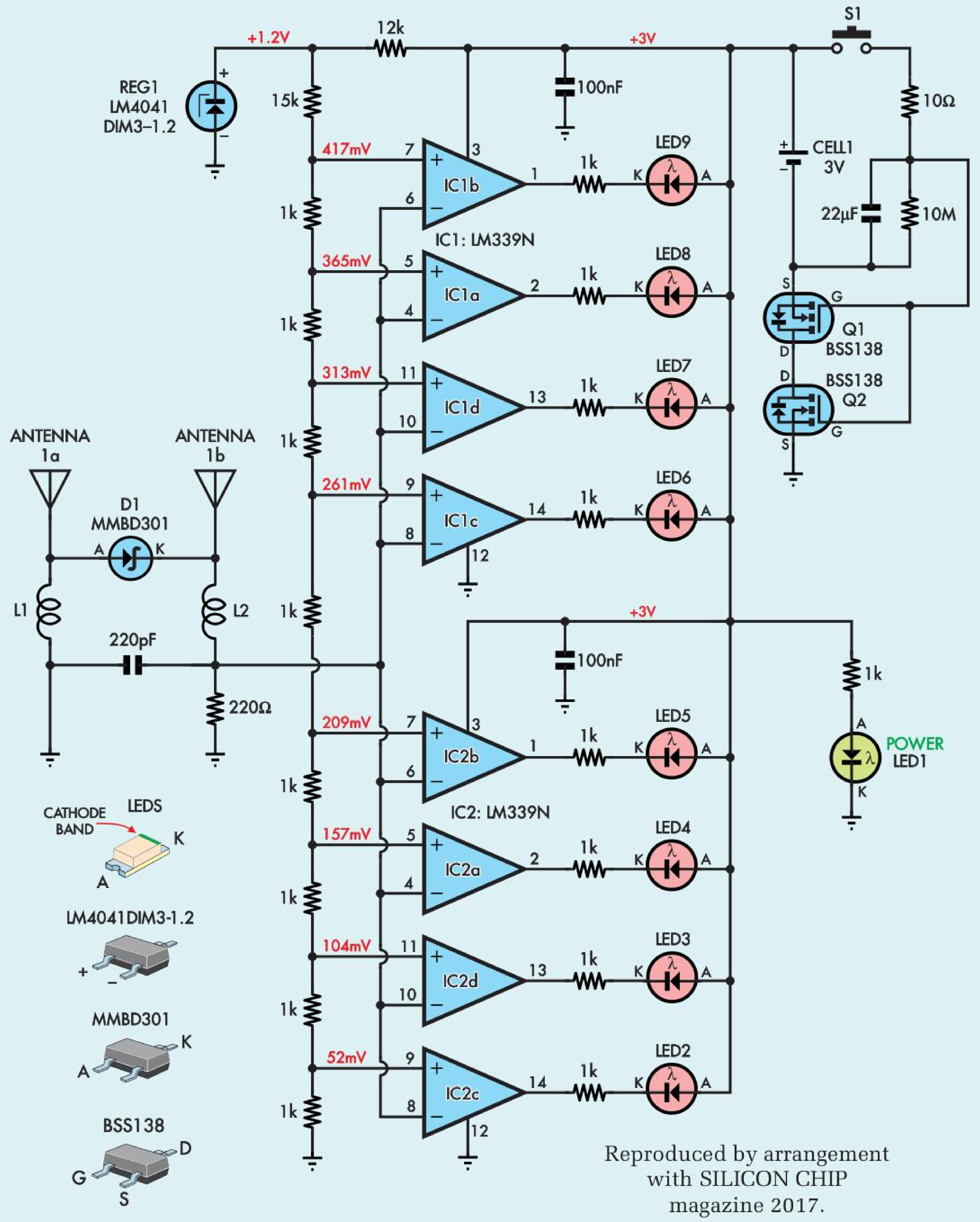
The original *ETI* project used a tiny moving-coil analogue meter (as used in squillions of tape recorders in those days) to display the received signal strength. This had the advantage of making the device entirely passive, ie, the received RF energy operated the meter and thus no battery was required.

However, while this was cheap and simple in those times, it would now result in a fairly bulky and moderately expensive unit, with the meter costing around £10 today. Our new design can be built for less than that in its entirety.

Instead of an analogue meter, we're using an 8-LED bargraph driven by two quad comparators, powered by the CR2032 lithium button cell.

Since you're only going to use this tester for a few minutes now and then, the button cell should last for years. The SMD parts used are compact and relatively inexpensive. The LEDs respond very quickly so you can easily see if the field is steady or pulsed and they're bright and easy to see, even at arm's length.

Having said that, if you wanted to, you could simply fit the detector diode, filter capacitor and loading resistor and measure the voltage developed across it with a multimeter (available for a fiver). It's up to you; this is the cheapest and simplest option, but of course it will be somewhat more awkward to use.



Reproduced by arrangement with SILICON CHIP magazine 2017. www.siliconchip.com.au

MICROWAVE LEAKAGE DETECTOR

Fig.1: the *Microwave Leakage Detector* circuit. The dipole consisting of antennas 1a and 1b picks up ~2.5GHz radiation and this is rectified by D1 and filtered by L1, L2 and the 220pF capacitor. The voltage developed across the 220Ω load resistor is indicated by an LED bargraph consisting of red LEDs2-9 which are driven by quad comparators IC1 and IC2. The whole unit is powered from a 3V lithium button cell and switched on (for a minute or two at a time) by pressing switch S1.

Circuit description

The complete circuit is shown in Fig.1. The dipole antenna is shown at left, connected to either end of the MMBD301 UHF diode. This then feeds the 220pF filter capacitor via low-value inductors L1 and L2. One end of the filter capacitor is grounded, while the other is loaded with a 220Ω resistor. The voltage developed across this resistor depends on the microwave field strength.

This voltage is fed to the inverting inputs of eight comparator stages, based on two LM339 quad comparators, which are cheap and will run from a 3V supply. The non-inverting inputs are connected to a resistor ladder which provides a series of linearly increasing voltages to each subsequent comparator stage. These are derived from a 1.2V reference voltage from REG1, which is reduced to around 417mV by a 15kΩ resistor, in combination with the 8kΩ resistance of the ladder.

If the voltage across the 220Ω load resistor is above 52mV, the output of IC2c will go low, pulling current through LED2 (the lowest red LED) and its 1kΩ current-limiting resistor. This

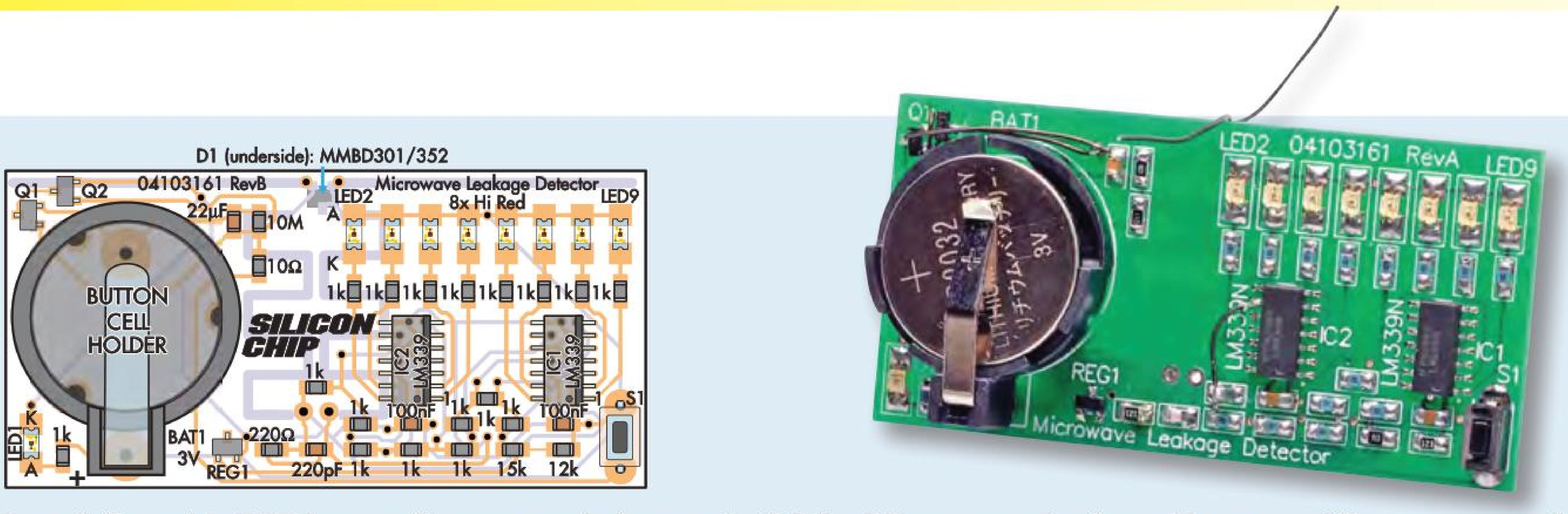


Fig.2: follow this PCB layout diagram and photo to build the *Microwave Leakage Detector*. All parts except for detector diode D1 go on the top of the board and most are SMDs, the exceptions being BAT1 and S1. The dipole antenna is on the bottom layer and is visible along the top of the board, as are the two zig-zag tracks that form the inductors below it. During construction, watch the orientation of IC1, IC2 and LEDs1-9. (Note: photo shows prototype board).

WARNING

DO NOT PUT THIS DETECTOR INSIDE A MICROWAVE OVEN AND TURN IT ON. IT WILL BE DESTROYED IMMEDIATELY!

You may think that this is a silly warning but we understand that Dick Smith Electronics had a number of similar kits returned in a rather melted condition because people had done just that!

resistor sets the LED current to around 1mA, sufficient for a high-brightness SMD LED to be quite visible. Similarly, if the voltage goes above 104mV, LED3 also lights, and so on. Above 417mV, all eight red LEDs (LED2-LED9) will be lit.

LED1 is on whenever the circuit is powered and similarly draws around 1mA. IC1 and IC2 together draw around 1mA, for a total quiescent current of around 2.4mA and a maximum current draw of just over 10mA, with all LEDs lit.

REG1 is a shunt regulator (like a zener diode) and is fed from the 3V battery via a 12kΩ resistor, which sets the nominal current level to (3V – 1.2V) ÷ 12kΩ = 150µA. The current through the ladder is 1.2V ÷ (15kΩ + 8kΩ) = 52µA. That leaves around 100µA of bias current for REG1; the minimum specified for proper operation is 60µA. This means the circuit should work OK even if the cell voltage has dropped to 2.55V (which would make it quite flat).

The remaining components protect against a reversed battery and provide the power switch-on and auto-off timer. MOSFETs Q1 and Q2 are connected back-to-back (ie, in inverse series) so that they will block current flow from the battery regardless of its polarity.

With correct battery polarity, when switch S1 is pressed, the 22µF capacitor charges to a positive voltage via the 10Ω resistor and this brings the gates of Q1 and Q2 high, switching them on and powering the circuit. The 22µF capacitor is slowly discharged by its 10MΩ parallel resistor and once its voltage falls below the on-threshold of Q1 and Q2 (around 1.25V), the circuit shuts down. LED1 dims and eventually goes out.

If the battery is inserted backwards, pressing S1 simply pulls the gates of Q1 and Q2 negative with regards to their source terminals, which only serves to switch them off harder, so nothing should be damaged; the circuit simply won't operate.

To calibrate the circuit, we simply adjusted the value of the 220Ω load resistor until a full-scale reading was reached with fields just strong enough to set off the alarm on a commercial microwave leakage detector that we purchased.

Construction

The *Microwave Leakage Detector* is built on a double-sided PCB available from the *EPE PCB Service*, coded 04103161 and measuring 64 × 32mm. Most parts are surface-mount type and all but one are fitted on the top side of the board. The exceptions are the battery holder and power switch (both through-hole parts) and the RF diode (D1) which is soldered on the underside. Refer to the PCB overlay diagram, Fig.2, during assembly.

Start by fitting the SMDs on the top side, beginning with the two ICs. Note that these are oriented with pin 1 towards the bottom of the board. Pin 1 is normally indicated with a divot or dot in the corner of the part, but if there is no such marking, then you will instead need to identify the side of the package with the bevelled edge. Pin 1 is on that side.

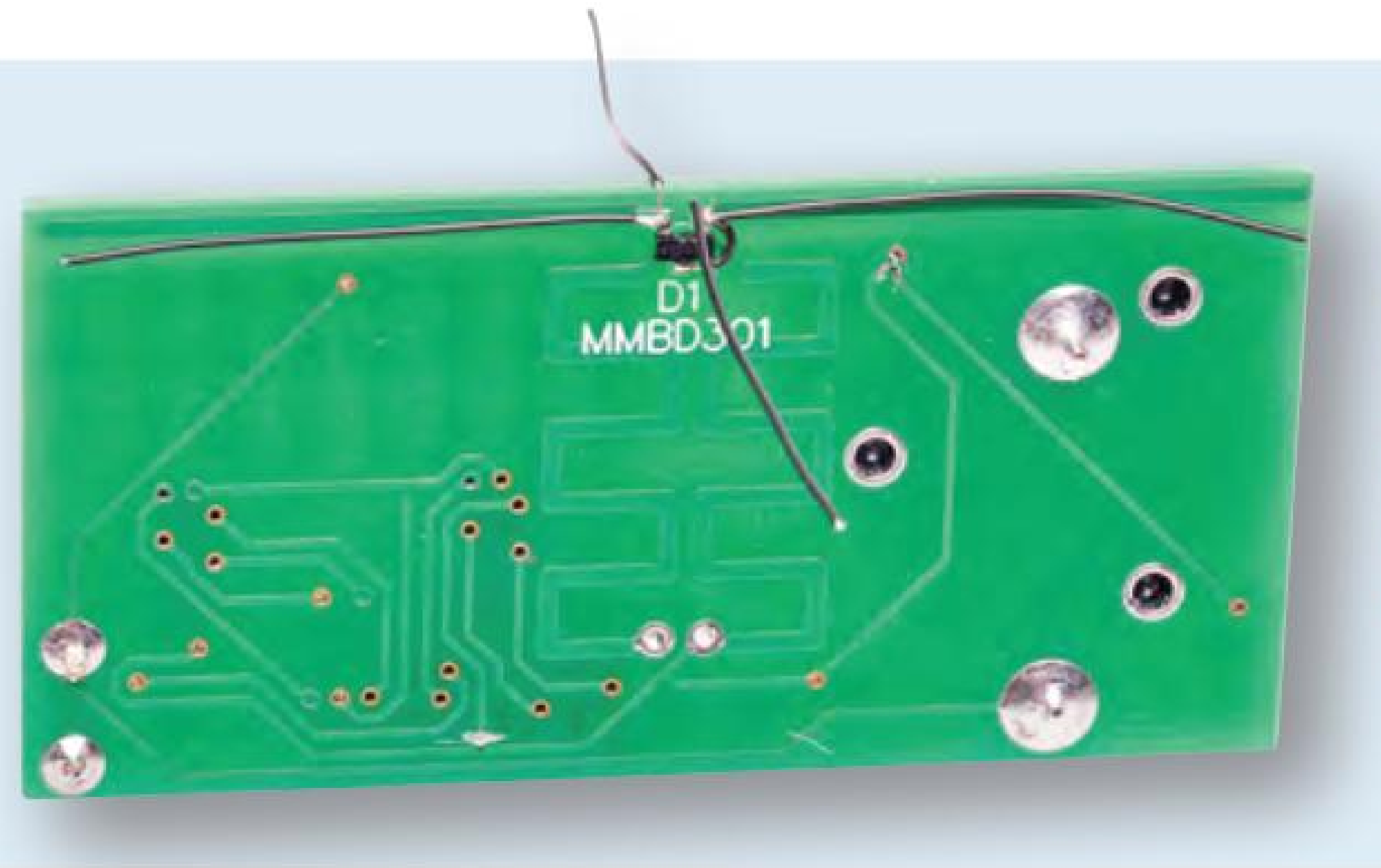
Melt a little solder onto one of the IC pads, then slide the IC into place while heating that solder. Check its orientation and pad alignment. If both are good, solder the diagonally opposite pin. Otherwise, re-heat the initial joint and nudge the part into place.

Finally, solder all the remaining pins and don't forget to add a little solder or flux to refresh the initial joint. If any of the pins are bridged with solder, clean them up with some solder wick. A small dab of flux paste will help this process.

Next, solder REG1, Q1 and Q2 in place. These are in more or less identical packages (SOT-23) so don't get them mixed up. Use a similar technique as for IC1 and IC2. Then fit the four ceramic capacitors. These are in 2 x 1.2mm (2012/imperial 0805) packages with no markings. The same basic technique as described above will work for these too.

Follow with the resistors, which are similar in size to the capacitors but have their value printed on top in tiny text. You will need a magnifying glass to read it.

The nine LEDs are next; eight red and one green (LED1). These are in larger packages at around 3.2 × 1.6mm. Use a DMM set on diode test mode to determine which end is the cathode – when the LED lights up, the black probe is connected to the cathode. Solder the LEDs with this end towards the 'K' on the PCB. Note that LED1's cathode faces towards the top of the PCB while LED2-LED9 are soldered with their cathodes facing the bottom.



The dipole antenna etched into the PCB works well but you can improve the sensitivity by soldering four 30mm lengths of wire to the pads on either side of D1, as shown here. Keep the wires straight; our got a little bent during photography.

Parts List

- 1 double-sided PCB, available from the *EPE PCB Service*, coded 04103161, 64 × 32mm
- 1 20mm button cell holder, through-hole (BAT1)
- 1 CR2032 cell (BAT1)
- 1 micro SPST tactile pushbutton switch (S1)
- 1 80mm length of 30mm-diameter clear heatshrink tubing (optional)
- 4 30mm lengths thin, stiff insulated wire (optional) (antenna for improved signal pick-up)

Semiconductors

- 2 LM339, LM239, LM2901 or LM3302 quad comparators, 3.9mm wide SOIC-14 (IC1,IC2)
- 1 LM4041DYM3-1.2 micropower 1.2V shunt regulator, SOT-23 (REG1)
- 2 BSS138 logic-level N-channel MOSFETs, SOT-23 (Q1,Q2)
- 1 green high-brightness LED, SMD 3216/1206 (LED1)
- 8 red high-brightness LEDs, SMD 3216/1206 (LED2-LED9)
- 1 MMBD301 single or MMBD352 dual Schottky hot-carrier diode (D1)

Capacitors (all SMD 2012/0805)

- 1 22μF 6.3V X5R
- 2 100nF 50V X7R
- 1 220pF 50V C0G/NP0

Resistors (all 1% SMD 2012/0805)

- 1 10MΩ
- 1 15kΩ
- 1 12kΩ
- 17 1kΩ
- 1 220Ω
- 1 10Ω

Now you can flip the PCB over and fit D1 before fitting the final two components, BAT1 and S1, on the top side.

Testing

Insert the CR2032 cell into the holder, with the positive side up. Press S1 and check that green LED1 lights up. It should stay lit for a minute or so, then dim and eventually go out. Red LEDs LED2-LED9 should remain off. If they switch on, either there is something wrong with the circuit or you are in a rather strong microwave field and should probably move!

Most constructors will have access to a Wi-Fi router of some sort and this is the easiest way to test the device, especially if you have the type with one or more external stub or whip antennas. With the unit switched on, hold it up alongside one of the router's antennas with its on-board dipole aligned with the antenna.

Assuming there is some network activity (and there usually will be, if only because the router is broadcasting its SSID), you should see some of LED2-LED9 light up and flicker as the router transmits bursts of data. Depending on how close you're holding the device, some bursts may be strong enough to light up all eight LEDs while others may result in just a few LEDs lighting. Bursts that light up all LEDs aren't necessarily hazardous as they will be quite brief, so the total radiated energy should be low.

Rotate the unit and note how quickly its sensitivity drops if it is not aligned with the radiated field. This is why, when checking a microwave oven, you will need to rotate the device as you move it around the oven.

Improving the antenna

While the dipole etched into the PCB works, we found that by soldering four 30mm lengths of thin, stiff insulated wire to the pads on either side of D1, the detector can be made less sensitive to antenna orientation. Basically, two of the pieces of wire are soldered directly in parallel to the PCB tracks while the other two are perpendicular, sticking out the front and back of the board (see photo).

We used Kynar but you could also use 'bell wire', which is a light-duty solid copper core insulated wire that was historically used for telephones. Make sure that it can't short to anything – you may need to insulate the ends with some thin heatshrink or a dob of silicone sealant.

It's still a good idea to hold the board so that one dipole or the other is in the assumed field direction. However, even if it's not quite perfectly aligned, you're more likely to get a reading with this arrangement.

This does make fitting heatshrink tubing over the PCB somewhat more tricky but it can still be done. You would need to solder the two parallel antenna wires, fit the tubing, shrink it down, then cut a couple of small holes and solder the perpendicular wires in place.

It may seem odd soldering antennas in parallel with the PCB tracks that act as antennas, but it's important because the impedance of the PCB tracks is much higher than the thin, circular cross-section wire. So the wire antennas will dominate the response unless they are fitted in pairs as described.

Using it

Pressing S1 switches the unit on for 1-2 minutes. You can hold down S1 or press it regularly to keep the unit on while you are using it. It will then switch off by itself.

The LED bargraph indicates the voltage generated across a 220Ω load resistor, in roughly 50mV steps. Thus the segments correspond roughly to received power levels of 11μW, 45μW, 100μW, 180μW, 284μW, 410μW, 556μW and 727μW. The danger level is generally considered to be 5mW/cm^2; however, we need to determine how effectively our unit picks up the radiation in order to calibrate the bar graph response.

We compared the response of the bargraph against a commercial microwave leakage detector and found that, with the 220Ω load resistor, a full-scale reading (ie, all eight red LEDs lit) corresponded pretty closely to 5mW/cm^2 (the legal limit, above which it is considered hazardous) on the commercial detector. This assumes the dipole is in alignment with the field, which we determined by rotating the detector for maximum response.

Operate the oven

The oven needs to be operating in order to check for leaks, but it's a bad idea to operate a microwave with nothing in it. Simply fill a bowl or mug with cold water and microwave this for a few minutes while testing, then tip the water out. Take care as it may be very hot; it's best to put in enough water to avoid it boiling during the test period.

So, if you want to check that your microwave is safe, start heating some water at full power, then switch the detector on and move it around the outside of the door – both the front face and around the sides. Also check around the edges of the window.

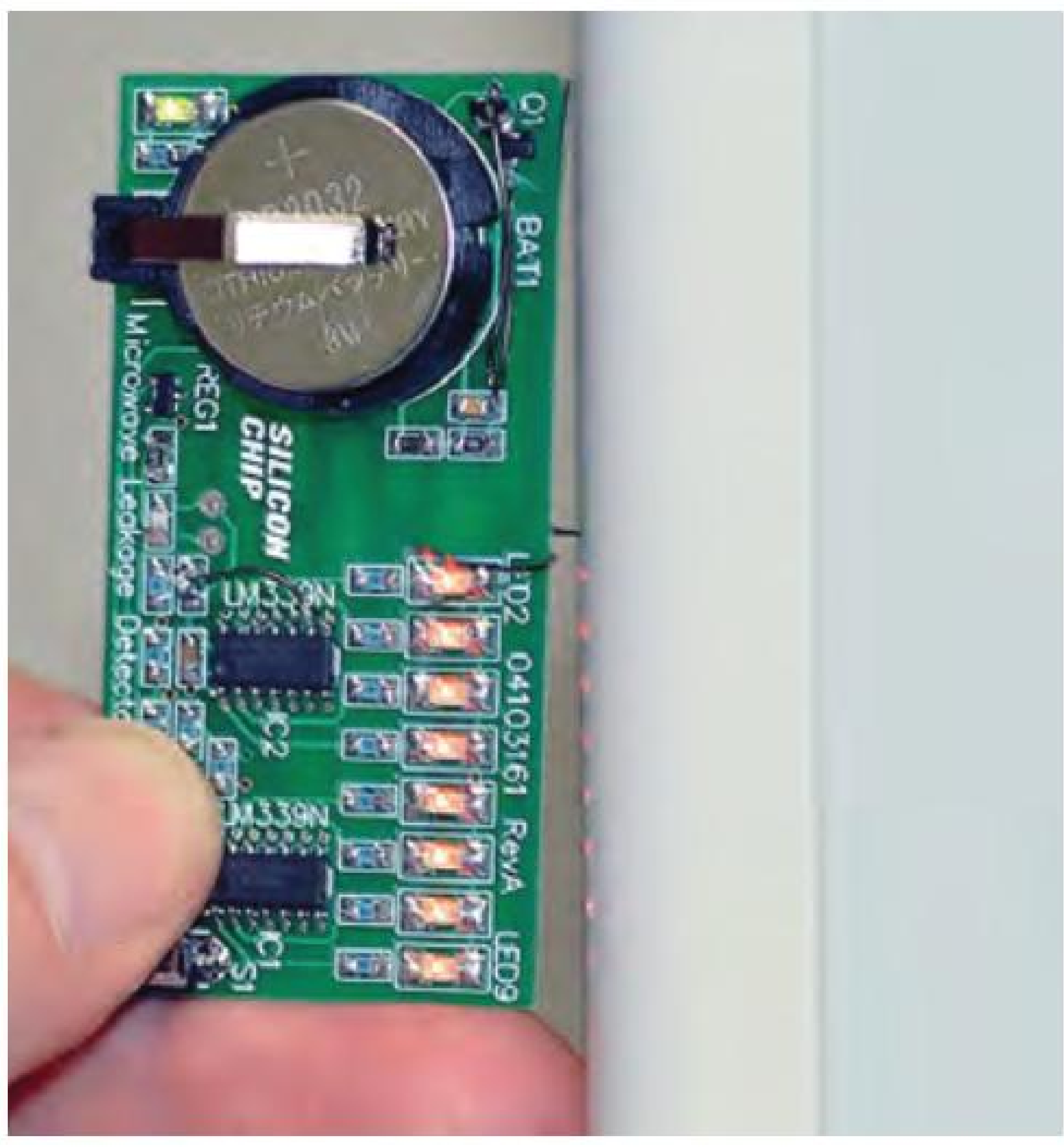
It's best to hold it such that the dipole is facing across the edge of the door. In other words, when holding it at the front of the oven, point the dipole at the centre of the door and when holding it at the sides, align the dipole so that it is pointing to the back of the oven.

Note that because the contents of the oven are normally on a rotating tray, the leakage field will change over time, as the contents will interact with the field. That means you will need to move the detector slowly and pause if you get a reading to see what it will peak at, at that location. Doing multiple sweeps is also a good idea.

Antenna distance

Generally, keep the antenna around 50mm from the oven as you sweep. But while this is the specified distance for the legal limit, the relatively long wavelength of microwave radiation (~12cm) means it's possible that the field strength could actually be higher further away from the oven, due to constructive and destructive interference. So a second sweep at a somewhat greater distance would not hurt.

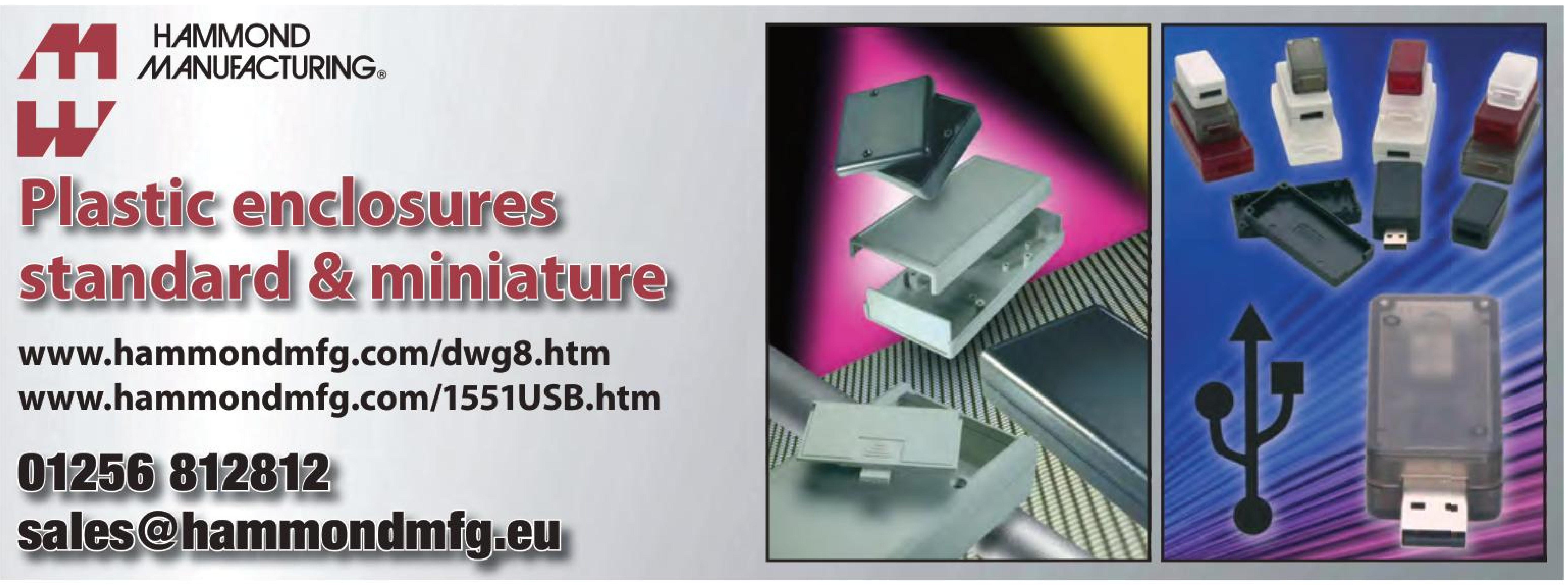
If you want to use the detector to sense 2.4GHz radio signals, it's simply a matter of holding it as close to the radiating antenna as you can and rotating it until you get a response. Note that while it's quite effective at picking up Wi-Fi router transmissions, at the low power levels generated by battery-powered Wi-Fi devices, mobile phones and other 3G/4G devices, you may have difficulty picking up enough energy to light the LEDs.



The microwave oven is checked while it is operating by moving the *Microwave Leak Detector* around the edge of the door and the edge of the viewing window. If all eight bargraph LEDs light then there is excessive leakage and the oven can be considered hazardous. Note: this is closer than you would normally hold it.

Check out our website:
www.epemag.com

Looking to advertise?
Contact Stewart Kearn on:
01202 880299
or email
stewart.kearn@wimborne.co.uk


HAMMOND MANUFACTURING®
Plastic enclosures standard & miniature
www.hammondmfg.com/dwg8.htm
www.hammondmfg.com/1551USB.htm
01256 812812
sales@hammondmfg.eu

EXCLUSIVE OFFER

Win a Microchip BM64 Bluetooth Audio Evaluation Board

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip BM64 Bluetooth Audio Evaluation Board (BM-64-EVB-C2).

This board enables easy development with Microchip's new IS206X family of SoC devices and modules, which offer Bluetooth Low Energy (BLE) capability. Uniquely engineered for speakers, headsets and gaming headphones, the IS206X flash-based platform offers flexibility and powerful design features, allowing audio manufacturers to easily incorporate wireless connectivity in streaming music and voice-command applications.

The BM64 Bluetooth Audio Evaluation enables the user to evaluate and demonstrate the functionality of the BM64 Class 2 stereo audio module. The BM-64-EVB-C2 includes an integrated configuration and programming interface for plug-and-play capability, and also has status LEDs which enable rapid prototyping and faster time to market.

Along with the BM-64-EVB-C2, software tools and applications are provided to demonstrate the Bluetooth connections to the on-board BM64 stereo audio module and to optionally configure or program it. Microchip's highly-integrated module solutions are self-contained, low-power, and fully-certified for designers seeking to develop wearable or IoT devices without any Bluetooth Low Energy IP Stack or RF experience.

The BM64 EVB has two USB ports that can be connected to the host PC using a micro-USB cable. Other BM64 Bluetooth Audio Evaluation Board features include: • Based on the fully-certified Bluetooth 4.2 BM64 Class 2 stereo audio module • Powered by a PC host using a micro-USB cable or by connecting a Li-Ion battery • Built-in 3W Class-D stereo audio amplifier • Built-in Near Field Communication (NFC) • Stereo audio output for high-quality audio • Easy access to I/O pins • Connection and data status LEDs.

WORTH
$27.99
(approx. £23.00)
EACH

BM64_EVB
MICROCHIP
SPK
MIC
LINE_IN
V1•1
EXT MCU/DSP

HOW TO ENTER

For your chance to win a Microchip BM64 Bluetooth Audio Evaluation Board, visit: **www.microchip-comps.com/epe-m64blue** and enter your details in the online entry form.

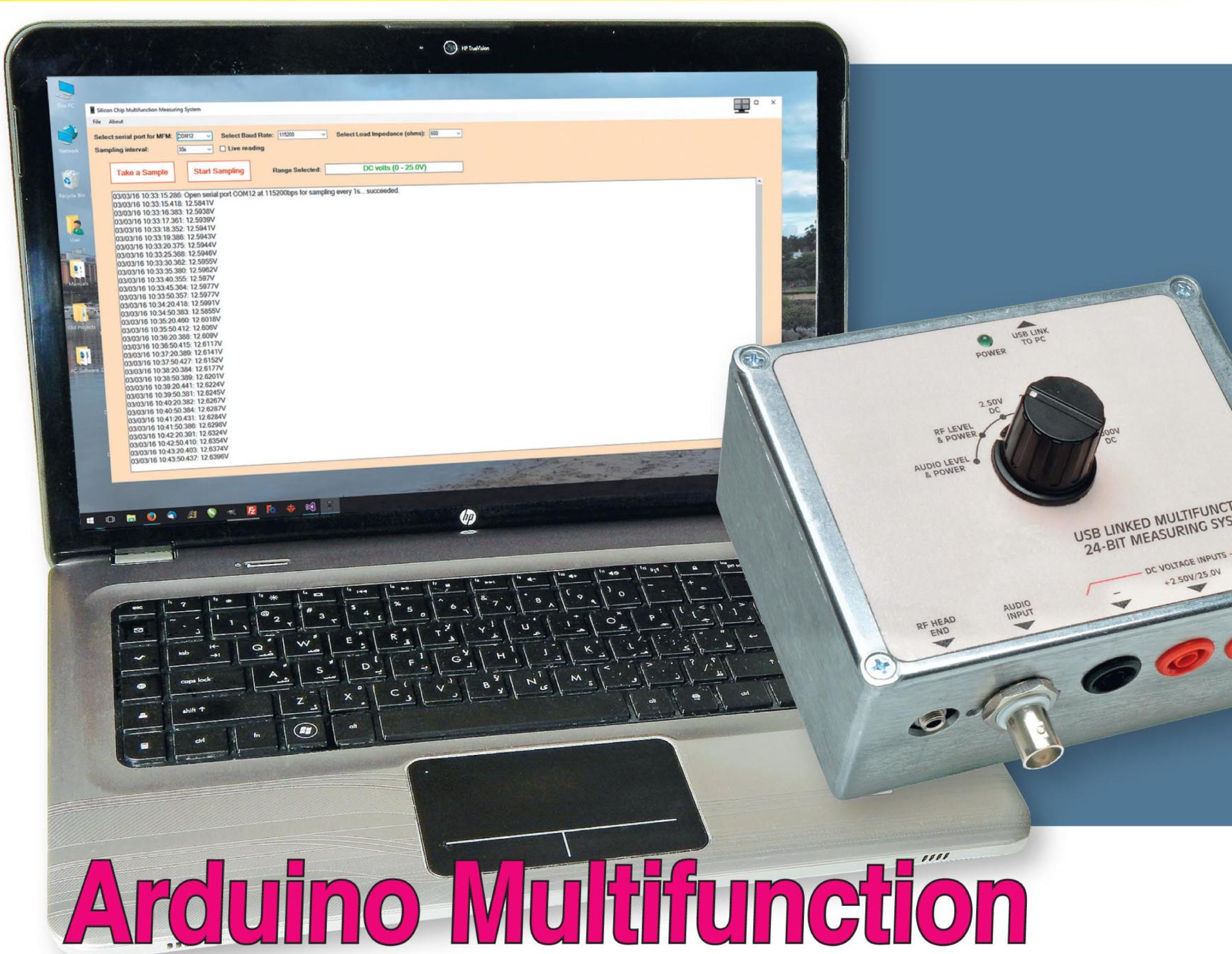
CLOSING DATE

The closing date for this offer is 30 April 2017.

December 2016 ISSUE WINNER

Mr Ed Rees, who works at Reeset Electronics, Berkshire, UK

He won a Microchip Explorer 16/32 Development, valued at £90.00



Select serial port for MFM: COM12

Select Baud Rate: 115200

Select Load Impedance (ohms): 600

Sampling interval: 30s

☐ Live reading

Range Selected: DC volts (0 - 25.0V)

```
03/03/16 10:33:15.286: Open serial port COM12 at 115200bps for sampling every 1s... succeeded.
03/03/16 10:33:15.418: 12.5841V
03/03/16 10:33:16.383: 12.5938V
03/03/16 10:33:17.361: 12.5939V
03/03/16 10:33:18.352: 12.5941V
03/03/16 10:33:19.386: 12.5943V
03/03/16 10:33:20.375: 12.5944V
03/03/16 10:33:25.368: 12.5946V
03/03/16 10:33:30.362: 12.5955V
03/03/16 10:33:35.380: 12.5962V
03/03/16 10:33:40.355: 12.597V
03/03/16 10:33:45.364: 12.5977V
03/03/16 10:33:50.357: 12.5977V
03/03/16 10:34:20.418: 12.5991V
03/03/16 10:34:50.383: 12.5855V
03/03/16 10:35:20.460: 12.6018V
03/03/16 10:35:50.412: 12.606V
03/03/16 10:36:20.388: 12.609V
03/03/16 10:36:50.415: 12.6117V
03/03/16 10:37:20.389: 12.6141V
03/03/16 10:37:50.427: 12.6152V
03/03/16 10:38:20.384: 12.6177V
03/03/16 10:38:50.389: 12.6201V
03/03/16 10:39:20.441: 12.6224V
03/03/16 10:39:50.381: 12.6245V
03/03/16 10:40:20.382: 12.6267V
03/03/16 10:40:50.384: 12.6287V
03/03/16 10:41:20.431: 12.6284V
03/03/16 10:41:50.386: 12.6298V
03/03/16 10:42:20.391: 12.6324V
03/03/16 10:42:50.410: 12.6354V
03/03/16 10:43:20.403: 12.6374V
03/03/16 10:43:50.437: 12.6396V
```

Arduino Multifunction 24-Bit Measuring Shield

Here's a low-cost PC-linked measuring system project which provides four accurate DC voltage measurement ranges, together with an audio frequency level and power meter, plus an optional RF level and power meter that can operate to 500MHz.

WANT TO accurately measure voltages, decibels and power levels using an Arduino? This design combines a 4-range, 24-bit DC voltmeter with both audio frequency and RF level and power meters. The audio meter can measure up to 60V RMS (up to 900W into a 4Ω load) while the RF section will measure up to 1kW into a 50Ω load, with a frequency range extending up to around 500MHz.

Apart from the RF measurement head, everything fits into a small die-cast aluminium box (119 × 94 × 57mm) which is hooked up to a PC via USB. No separate power supply is required. The RF Head is tiny; just 51 × 51 × 32mm and connects to the main box via a standard 3.5-to-3.5mm tip/ring/sleeve (TRS) (or stereo phono jack) cable.

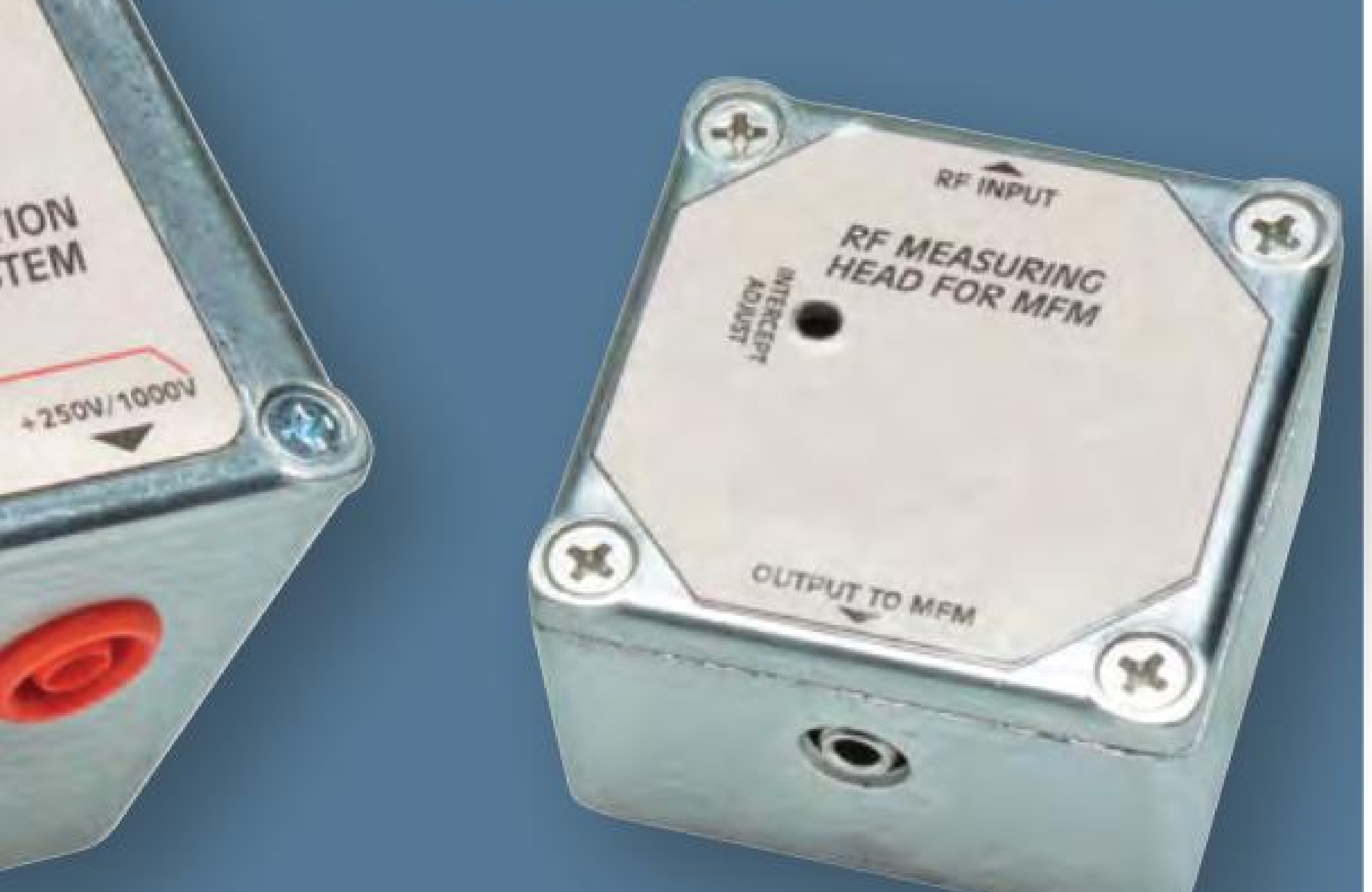
The unit is designed to be controlled from a Windows PC (the software is for Windows 7 or later) but you could also write your own Arduino 'sketch' to suit other measurement tasks.

In short, this is a seriously useful and accurate test instrument that can be built at moderate cost. Refer to the specification panel for more details.

What's inside the box

Fig.1 on the facing page shows a simplified block diagram of the *Multifunction*

Part 1: By Jim Rowe


ION
TEM
+250V/1000V
RF INPUT
RF MEASURING
HEAD FOR MFM
INTERCEPT
ADJUST
OUTPUT TO MFM

The *MFM* shield PCB is housed in a metal diecast case measuring 119 × 94 × 57mm. The optional *RF Head* PCB is housed in a small diecast case measuring 51 × 51 × 32mm.

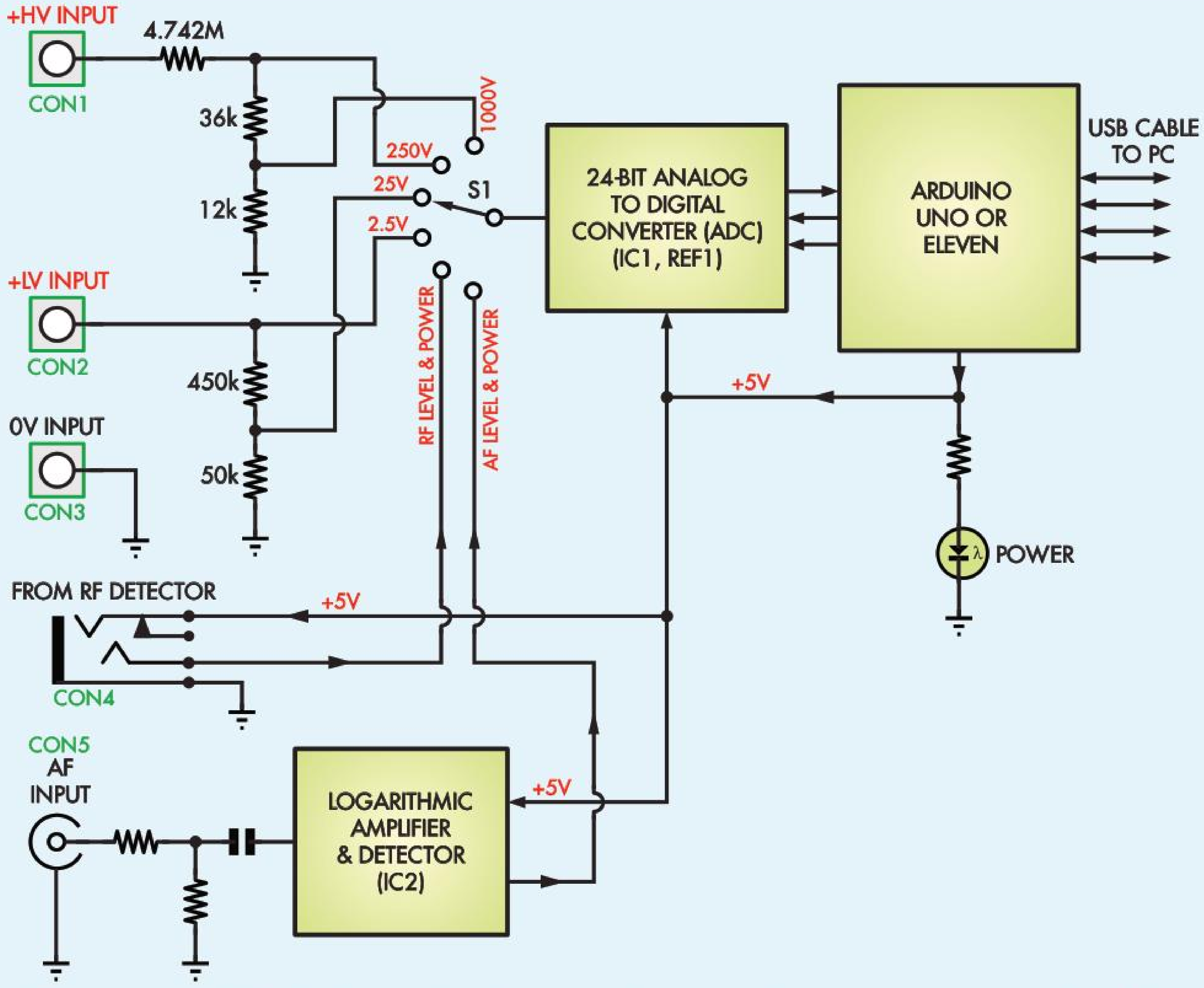
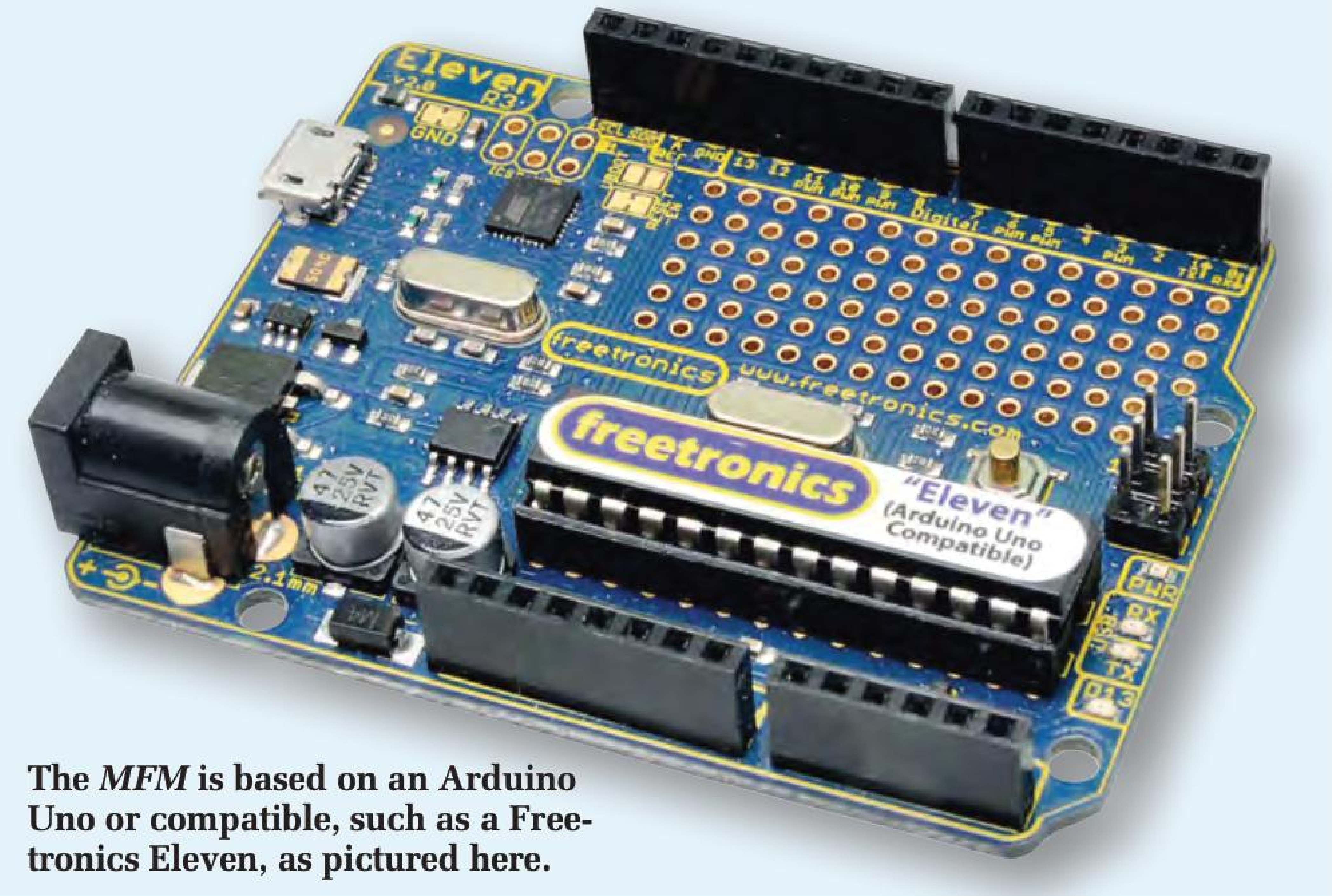

+HV INPUT
4.742M
CON1
36k
12k
1000V
250V
25V
2.5V
S1
24-BIT ANALOG
TO DIGITAL
CONVERTER (ADC)
(IC1, REF1)
ARDUINO
UNO OR
ELEVEN
USB CABLE
TO PC
+LV INPUT
CON2
450k
50k
0V INPUT
CON3
RF LEVEL & POWER
AF LEVEL & POWER
+5V
POWER
FROM RF DETECTOR
+5V
CON4
CON5
AF
INPUT
LOGARITHMIC
AMPLIFIER
& DETECTOR
(IC2)
+5V

Fig.1: a simplified schematic showing the general operating principle of the *Multifunction Meter*. There are four inputs: low and high-voltage DC, audio level/power and RF level/power. S1 connects these inputs to a high-precision analogue-to-digital converter (ADC) which is controlled by the Arduino. This in turn passes the measured values on to the PC for logging or display. IC2 provides AC-to-DC conversion for audio signals, while an identical chip mounted off-board (but configured differently) feeds in RF level and power measurements via jack CON4.


Eleven
R3
freetronics
www.freetronics.com
"Eleven"
(Arduino Uno Compatible)
2.1mm

The *MFM* is based on an Arduino Uno or compatible, such as a Freetronics Eleven, as pictured here.

Meter (*MFM*). At its heart is an Arduino Uno or compatible (eg, Freetronics Eleven or Duinotech Classic). This is shown at upper right and it controls the rest of the circuitry, including the USB link to the PC. The USB cable also provides 5V DC to power all of the meter's circuitry.

Coupled closely to the Arduino is the digital sampling 'engine' shown to its left. This comprises a Linear Technology LTC2400 24-bit precision ADC (analogue-to-digital converter), together with an LT1019ACS8-2.5V precision voltage reference. This combination forms a high-resolution, high accuracy digital DC voltmeter with a basic range of 0-2.5V, a resolution of 150nV (nanovolts!) and a basic accuracy of around ±0.06% (ie, ±1.5mV).

The LTC2400 is a very impressive device. It comes in an SO-8 SMD package, uses delta-sigma conversion technology and connects to the Arduino via a flexible 3-wire interface compatible with SPI and Microwire communication protocols. Other nice features include a built-in pin-selectable notch filter providing better than 110dB rejection at either 50Hz or 60Hz (ie, to reject mains hum fields), very low offset and noise, and a low supply current of only 200µA. It operates from a single 2.7-5.5V supply.

Range switch S1 controls the connections between the ADC and the various inputs and has six positions. Four of these are for the DC voltage ranges, while the remaining two are used for the *Audio Level & Power* and the *RF Level & Power* ranges respectively.

In the third position of S1, the +LV input connector CON2 is connected directly to the input of the ADC, giving a measurement range of 0-2.5V. In the next position, the ADC is connected via a 10:1 voltage divider, giving a

Features and specifications

- **Description:** A PC-linked digital measurement system combining the functions of an accurate DC voltmeter, an audio level and power meter and an RF level and power meter. PC link is via USB with an adjustable sampling rate. The application software allows saving data in CSV format for later loading, plotting or analysis.
- **Power supply:** All power comes from the host PC. Draws less than 65mA from the USB port (<325mW @ 5V).

DC Voltmeter

- **Four ranges**: 0-2.5V, 0-25V, 0-250V and 0-1000V.
- **Resolution:** 24 bits (1 part in 16,777,216) corresponding to 150nV, 1.5μV, 15μV and 60μV for each range.
- **Basic accuracy:** approximately ±0.06% on 2.5V range (±1.5mV), ±0.5% on higher ranges (±125mV, ±1.25V and ±5V respectively).
- **Input resistance:** 500kΩ on the 2.5V and 25V ranges, 4.79MΩ on the 250V and 1000V ranges.

Audio Level & Power Meter

- **Input range:** 4.2mV RMS (–37.5dBV) to 60V RMS (+35.5dBV) (83dB range)
- **Frequency response:** from below 20Hz to above 200kHz.
- **Input resistance:** 60kΩ.
- **Power readout:** watts, dBm and dBV for load impedances of 600Ω, 75Ω, 50Ω, 32Ω, 16Ω, 8Ω, 6Ω, 4Ω or 2Ω.
- **Maximum readings:**
  600Ω: 6W, +37.8dBm
  75Ω: 48W, +46.8dBm
  50Ω: 72W, +48.6dBm
  32Ω: 112.5W, +50.5dBm
  16Ω: 225W, +53.5dBm
  8Ω: 450W, +56.5dBm
  6Ω: 600W, +57.8dBm
  4Ω: 900W, +59.5dBm
  2Ω: 1800W, +62.5dBm

RF Level & Power Meter

- **Input range:** 15.8mV RMS (–36dBV) to 223.6V RMS (+47dBV) (83dB range)
- **Frequency response:** approximately 10kHz to 500MHz.
- **Input resistance:** 101kΩ.
- **Power readout:** watts, dBm and dBV for load impedances of 75Ω or 50Ω (600Ω, 32Ω, 16Ω, 8Ω, 6Ω, 4Ω and 2Ω modes also available).
- **Maximum power readings:**
  75Ω: 667W, +58.2dBm
  50Ω: 1000W, +60.0dBm
- **Minimum readings:**
  75Ω: 3.33μW, –24.8dBm
  50Ω: 4.99μW, –23.0dBm

Front panel artwork

Artwork for the two labels can be downloaded from the *EPE* website as a PDF file.

Print these out (or photocopy Fig.6), then laminate them in clear plastic for protection and then finally attach them using thin double-sided tape.

measurement range of 0-25V. In either case, the load impedance is 500kΩ.

In the fifth / sixth positions of S1, the ADC input is connected to the +HV input at CON1 via a 2-step voltage divider giving a division ratio of 100:1 for the fifth position and 400:1 for the sixth position. This gives two further DC voltage ranges of 0-250V and 0-1000V respectively.

The first position of S1 is used for the *Audio Level & Power* function, with the signal fed into a separate BNC input socket. Signal processing is performed by IC2, an Analog Devices AD8307ARZ logarithmic amplifier/detector device, which uses a progressive compression/successive detection technique to provide a dynamic range of more than 88dB with a linearity of ±0.3dB, at all frequencies between 20Hz and 100MHz.

In effect, the AD8307 is a wideband AC-to-DC converter with a logarithmic transfer function. It converts AC signals to a DC output voltage which varies from 0.25V to 2.5V, with a nominal slope of 25mV/dB. This can be adjusted via external components, as we shall see shortly.

Finally, the second position of switch S1 connects the ADC input to the tip of CON4, which interfaces with the *RF Detector Head*. We haven't included this circuitry in Fig.1, but it will be covered below. It's based on another AD8307 logarithmic amplifier detector, but with a different configuration, to allow it to operate at frequencies up to about 500MHz.

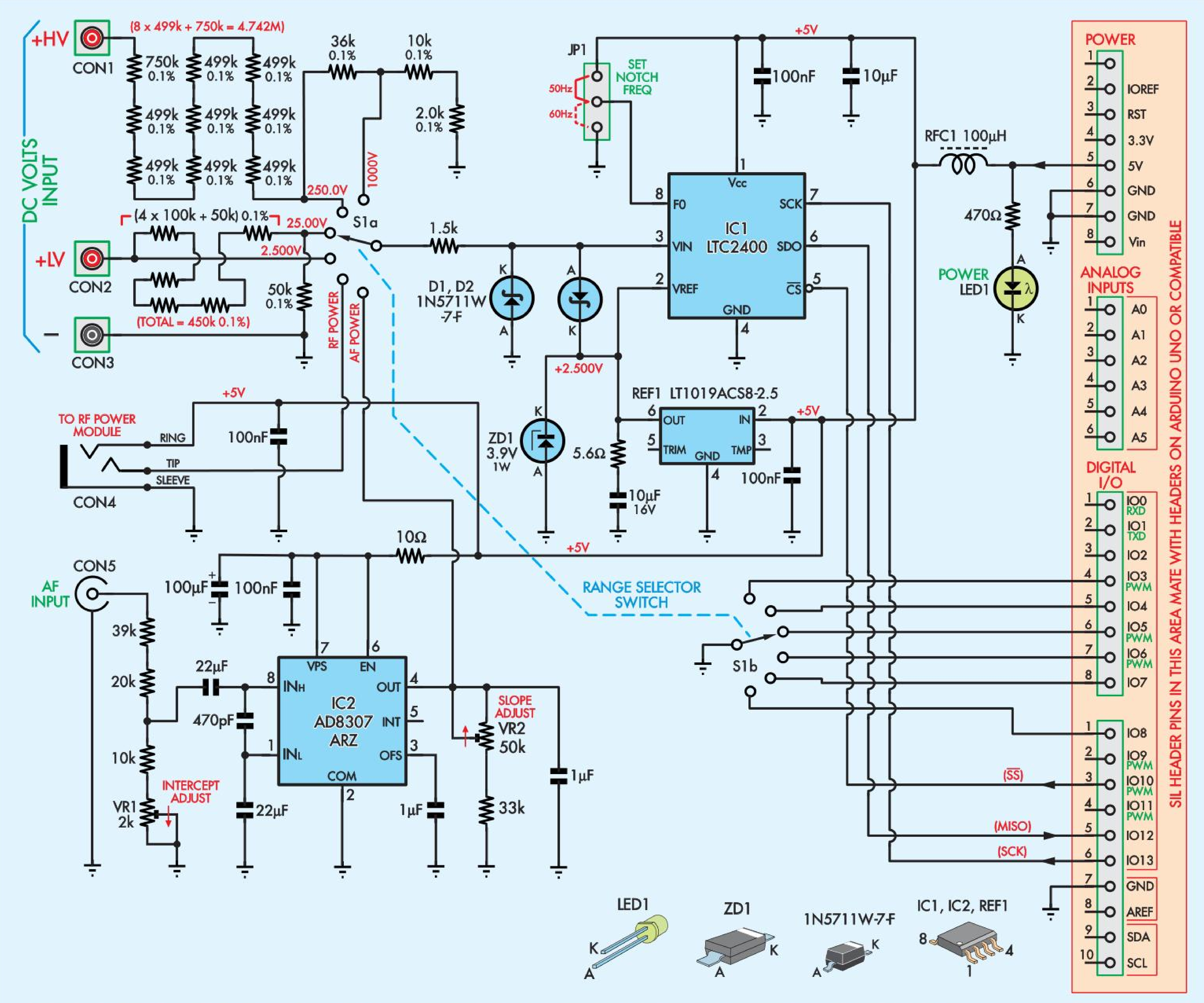
Circuit description

Fig.2 shows the full circuit diagram for the *Multifunction Meter's* main 'shield' PCB, ie, everything apart from the Arduino itself and the *RF Head*. The Arduino interface is via the SIL header pins shown on the right-hand side of the circuit, while the RF level and power measurement head connects via CON4 at centre left. More on this shortly.

Fig.2 includes the LTC2400 24-bit ADC (IC1) and LT1019ACS8-2.5 2.5V reference (REF1) which were both mentioned previously. Pin 3 of IC1 is the analog input (V_{IN}), with Schottky diodes D1 and D2 providing input overvoltage protection, in conjunction with a 1.5kΩ series resistor.

The 2.5V reference from REF1 is fed to pin 2 of IC1 (V_{REF}), while ZD1 and the series RC circuit between this pin and ground both reduce any noise present in the output of REF1 and limit any voltage rise of the 2.5V reference output due to accidental input voltage overload.

Pin 8 of IC1 is used to set its internal notch filter to either 50Hz or 60Hz, by connecting it to +5V or ground via JP1. Pins 5, 6 and 7 of IC1 form the SPI serial interface connecting it to the Arduino.


+HV
CON1
(8 x 499k + 750k = 4.742M)
750k 0.1%
499k 0.1%
36k 0.1%
10k 0.1%
2.0k 0.1%
1000V
250.0V
DC VOLTS INPUT
(4 x 100k + 50k) 0.1%
25.00V
2.500V
S1a
+LV
CON2
50k 0.1%
(TOTAL = 450k 0.1%)
–
CON3
RF POWER
AF POWER
1.5k
D1, D2 1N5711W -7-F
K
A
+2.500V
JP1
50Hz
60Hz
SET NOTCH FREQ
+5V
100nF
10µF
IC1 LTC2400
Vcc
F0
SCK
VIN
SDO
VREF
CS
GND
REF1 LT1019ACS8-2.5
OUT
IN
TRIM
GND
TMP
ZD1 3.9V 1W
5.6Ω
10µF 16V
100nF
RFC1 100µH
470Ω
POWER LED1
λ
TO RF POWER MODULE
RING
TIP
SLEEVE
CON4
100nF
10Ω
CON5
AF INPUT
100µF
100nF
39k
20k
10k
VR1 2k
INTERCEPT ADJUST
22µF
470pF
IC2 AD8307 ARZ
VPS
EN
INH
OUT
INT
INL
OFS
COM
SLOPE ADJUST
VR2 50k
33k
1µF
RANGE SELECTOR SWITCH
S1b
POWER
IOREF
RST
3.3V
5V
GND
Vin
ANALOG INPUTS
A0
A1
A2
A3
A4
A5
DIGITAL I/O
IO0 RXD
IO1 TXD
IO2
IO3 PWM
IO4
IO5 PWM
IO6 PWM
IO7
IO8
IO9 PWM
IO10 PWM
IO11 PWM
IO12
IO13
AREF
SDA
SCL
(SS)
(MISO)
(SCK)
SIL HEADER PINS IN THIS AREA MATE WITH HEADERS ON ARDUINO UNO OR COMPATIBLE
LED1
ZD1
1N5711W-7-F
IC1, IC2, REF1

ARDUINO MULTIFUNCTION 24-BIT MEASURING SHIELD

Fig.2: the full circuit diagram for the *MFM* shield (the optional RF power head and the components on the Arduino PCB are not shown). The input switching and attenuation circuitry is shown at upper left, while the 24-bit ADC (IC1) and associated components is at upper right. The audio level and power measurement circuitry is based on IC2 at lower left, while the Arduino interface headers are on the righthand side of the circuit.

Pin 5 is the 'slave select' (enable) input, while pin 7 is the serial clock (SCK) input. Sample data emerges from pin 6, the serial data output (SDO), which connects to the MISO (master in/slave out) serial input of the Arduino, via digital I/O pin 5 (IO12).

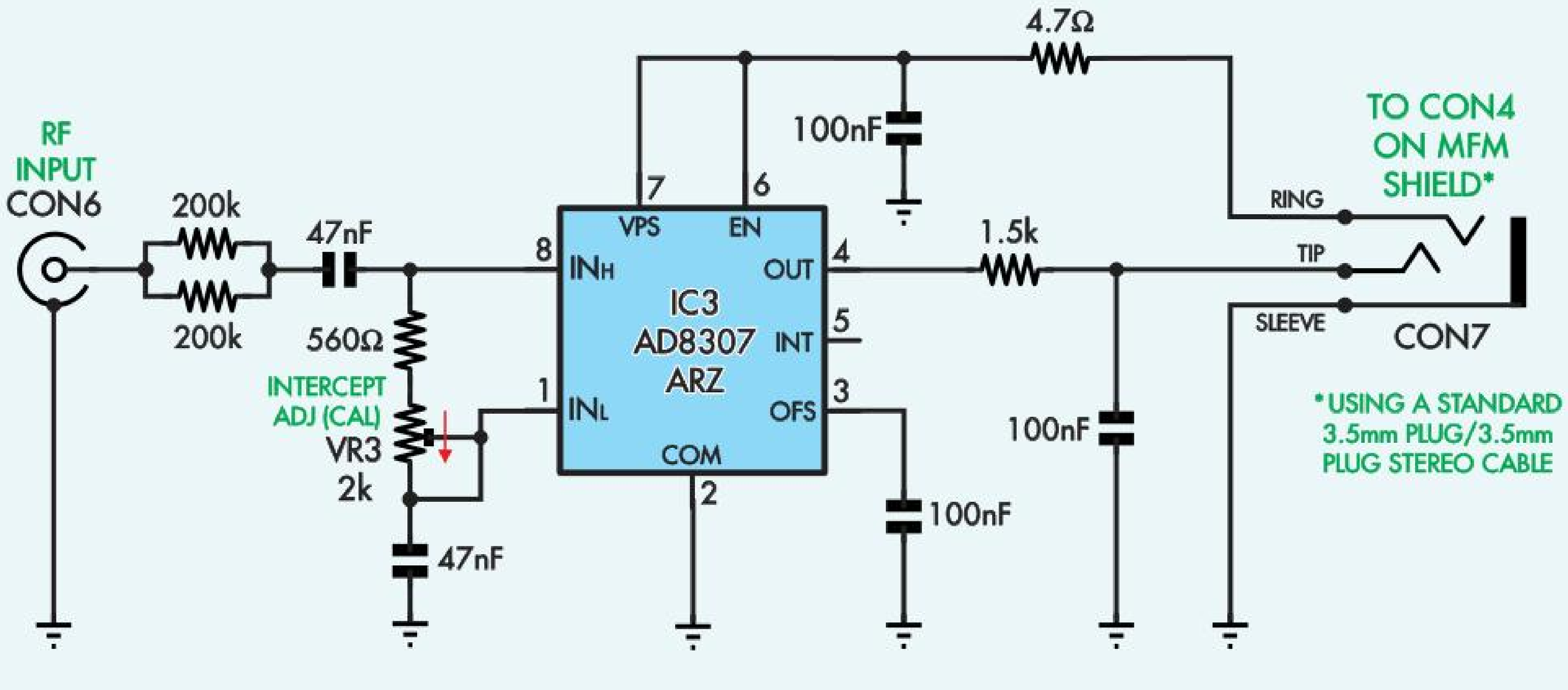
Fig.2 also shows a second pole for range switch S1 (S1b). This allows the Arduino to monitor which range the user has selected. Each position goes to a different digital input on the Arduino (pins IO3-IO8), while the rotor is grounded. These inputs have internal pull-up resistors so the firmware can tell the position of S1b (and thus S1a) by sensing which pin is pulled to ground.

The audio level and power meter circuitry is shown at lower left in Fig.2. As noted previously, this is based around IC2, an AD8307 logarithmic amplifier/detector. Its DC output voltage at pin 4 rises by a maximum of 25mV per decibel increase in the input AC voltage, which is applied between pins 8 and 1.

The 25mV/dB slope can be easily reduced by connecting an external load resistance, and this is the purpose of trimpot VR2 (50kΩ) and the 33kΩ series resistor. With VR2 adjusted to give a total of 50kΩ, IC2's output slope drops to 20mV/dB.

The audio input from CON5 is fed to pin 8 (IN_H) via a 60:1 resistive voltage divider and a 22µF capacitor, while pin 1 (IN_L) is connected to ground via another 22µF capacitor. Note that while the IN_H and IN_L pin names imply polarity, they are in fact interchangeable.

In determining the resistor values in the divider, we must consider the 1.1kΩ input resistance of the AD8307. So when trimpot VR1 in the lower leg of the nominal divider is set to 1kΩ (ie, to mid-range), the external lower leg resistance is 11kΩ, giving an effective lower leg resistance of 11kΩ // 1.1kΩ = 1.0kΩ. In conjunction with the upper leg resistance of 59kΩ, this gives the required 60:1 ratio.


RF INPUT
CON6
200k
200k
47nF
560Ω
INTERCEPT ADJ (CAL)
VR3
2k
47nF
4.7Ω
100nF
7
6
8
VPS
EN
INH
4
OUT
IC3
AD8307
ARZ
5
INT
1
INL
3
OFS
COM
2
1.5k
100nF
100nF
RING
TIP
SLEEVE
CON7
TO CON4 ON MFM SHIELD*
*USING A STANDARD 3.5mm PLUG/3.5mm PLUG STEREO CABLE

RF HEAD FOR ARDUINO MFM SHIELD

Fig.3: the optional *RF Head* circuit. Note the similarity to the audio level and power measurement circuitry in Fig.2; the main difference being that various component values and placements having been changed to expand the bandwidth out to 500MHz. 5V power comes from the main board via the ring connection of CON7, while the measurement output goes to the tip.

As a result, this section produces an output of 2.5V DC for an audio input of 60V RMS, falling at a rate of 20mV per dB, down to around 840mV DC with an input of 4.26mV RMS. That results in a measurement range from +35.5dBV to –47.5dBV, for signal frequencies from below 20Hz to above 200kHz.

You might wonder why VR1 is labelled 'Intercept Adjust'. This is because by adjusting the input divider ratio, it controls the input level that corresponds with 0V output from IC2.

The 470pF capacitor connected between input pins 8 and 1 of IC2 is there to attenuate input frequencies above about 300kHz. This is necessary because the AD8307 can respond to frequencies up to above 500MHz, which would result in the circuit being affected by RF interference. The 1µF capacitor between IC2's output pin 4 and ground acts as a noise filter, while the 1µF capacitor bypassing pin 3 (OFS) has a similar function.

The 5V DC rail that powers all these ICs comes from the PC's USB port, via the Arduino. Inductor RFC1 provides some RF filtering in case any unwanted signals have been picked up by the wiring. LED1, in conjunction with a 470Ω current-limiting resistor provides power indication.

RF input head

The RF input section is housed in a second smaller metal box and connects to CON4 on the main PCB via a 3.5mm 'stereo' cable. Fig.3 shows the circuit of this section and again, it's based on an AD8307 logarithmic amplifier/detector (IC3), with a changed configuration to make it suitable for measuring RF signals up to about 500MHz. We put it in a separate metal box, to prevent any RF radiation from affecting the operation of the rest of the circuit.

In this case, the input divider values provide a nominal division ratio of 158:1, while the output from pin 4 has no external resistance to ground, giving a nominal slope of 25mV/dB. As a result, the *RF Head* provides a 2.5V DC output for an RF input of 223V RMS, corresponding to 1000W into 50Ω or 666.6W into 75Ω. The minimum input voltage level is lower than

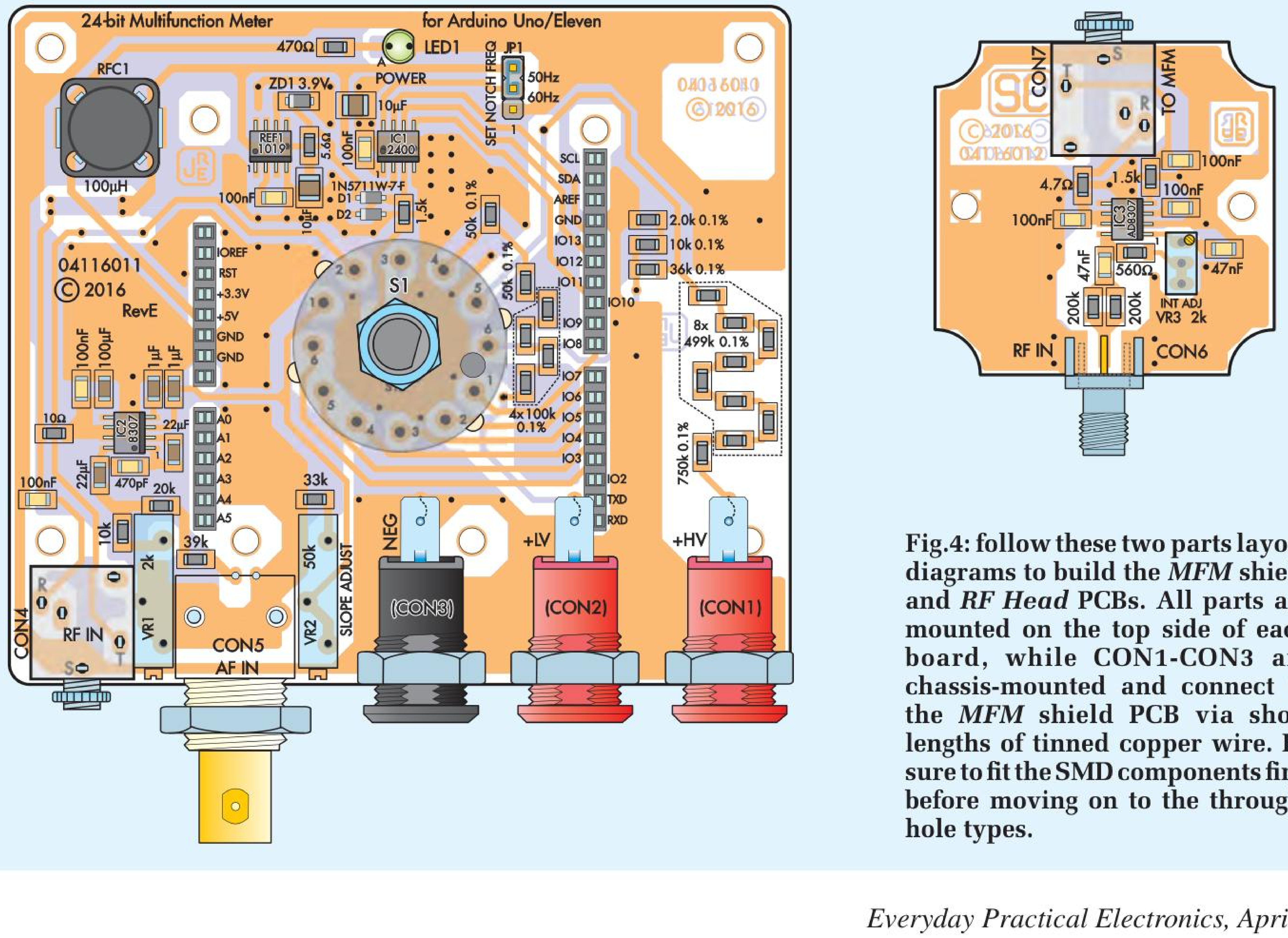

24-bit Multifunction Meter
for Arduino Uno/Eleven
470Ω
LED1
POWER
RFC1
100µH
ZD1 3.9V
10µF
REF1
IC1
SET NOTCH FREQ
JP1
50Hz
60Hz
1N5711W-7-F
D1
D2
04116011
© 2016
RevE
IOREF
RST
+3.3V
+5V
GND
GND
A0
A1
A2
A3
A4
A5
S1
SCL
SDA
AREF
GND
IO13
IO12
IO11
IO10
IO9
IO8
IO7
IO6
IO5
IO4
IO3
IO2
TXD
RXD
2.0k 0.1%
10k 0.1%
36k 0.1%
8x 499k 0.1%
4x 100k 0.1%
750k 0.1%
50k 0.1%
IC2 8307
22µF
10Ω
100nF
470pF
20k
33k
39k
10k
2k
50k
VR1
VR2
SLOPE ADJUST
CON4
RF IN
CON5
AF IN
NEG
(CON3)
+LV
(CON2)
+HV
(CON1)
04103012
© 2016
CON7
TO MFM
4.7Ω
1.5k
100nF
IC3 AD8307
47nF
560Ω
200k
INT ADJ
VR3 2k
RF IN
CON6

Fig.4: follow these two parts layout diagrams to build the *MFM* shield and *RF Head* PCBs. All parts are mounted on the top side of each board, while CON1-CON3 are chassis-mounted and connect to the *MFM* shield PCB via short lengths of tinned copper wire. Be sure to fit the SMD components first before moving on to the through-hole types.

7.07mV RMS, corresponding to 1μW into 50Ω or 0.66μW into 75Ω.

The *RF Head* receives its +5V DC power from the main *MFM* shield, via the same cable used to carry the output from IC3 back to CON4.

Construction

Most of the parts of the *MFM* are mounted on a single 96 × 83mm 'shield' PCB, available from the *EPE PCB Service* (code 04116011) which plugs directly into the Arduino PCB via SIL pin headers. Range switch S1 is at the centre of the shield PCB, while the RF and AF input connectors are at lower left. The complete assembly fits into a diecast box, along with three panel-mount DC input sockets (CON1-CON3) which are mounted just above the shield PCB.

All parts for the *RF Head* are fitted on a second PCB also available from the *EPE PCB Service* (code 04116012) which measures 42 × 41mm. This slips into a smaller diecast box (see photos). Use Fig.4 as a guide to assemble both boards. All components mount on the top sides of the boards.

Begin by fitting the SMD resistors, taking care not to overheat the 0.1% types. Follow with all of the SMD capacitors, which are not polarised.

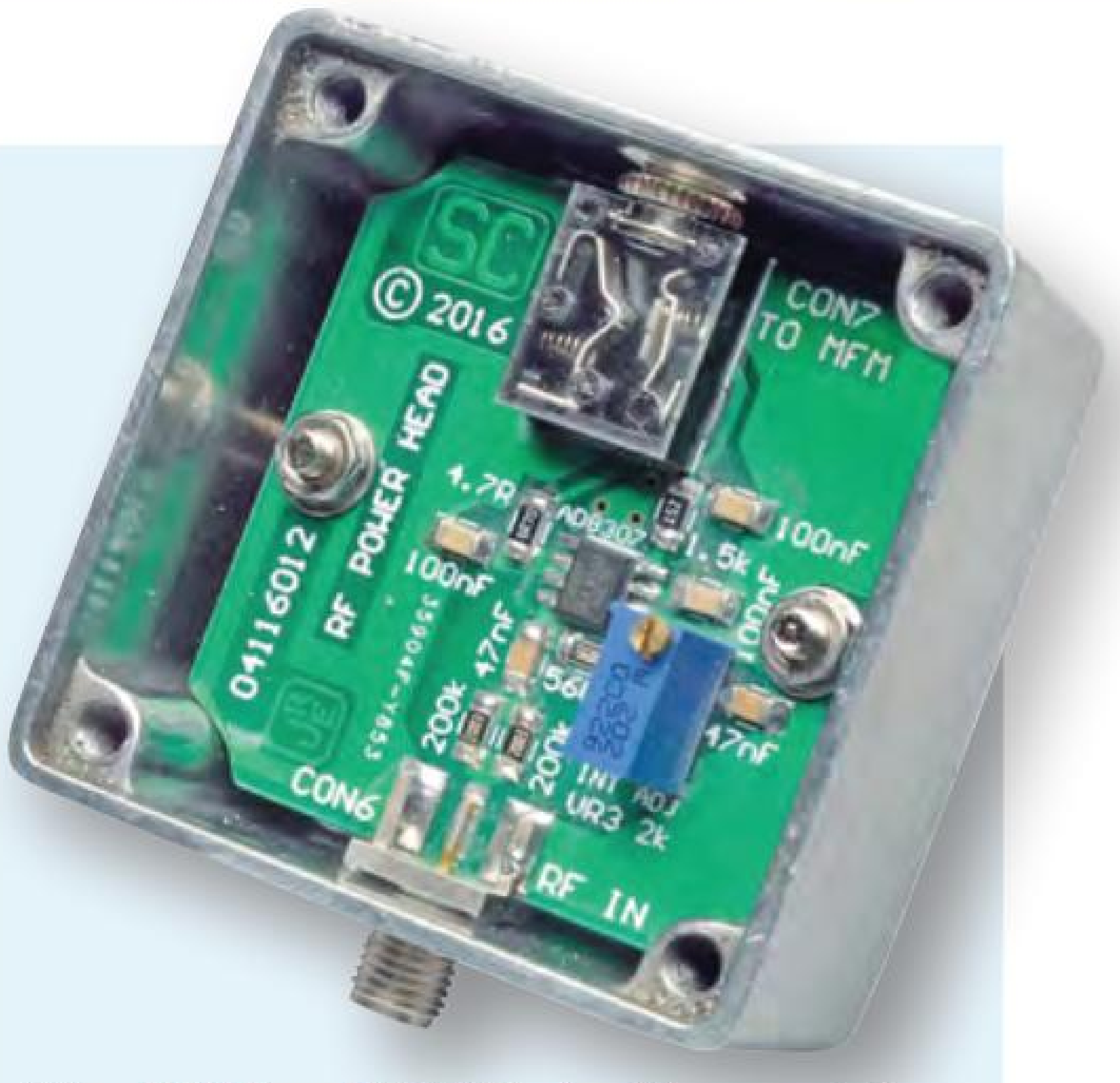
Next, mount the diodes (D1, D2 and ZD1) on the main PCB, then IC3 on the *RF Head* and IC2, REF1 and IC1 on the main PCB, preferably in that order. Finally, fit inductor RFC1. After that, only the through-hole parts are left.

Install the trimpots, taking care not to get VR1 and VR2 mixed up. BNC socket CON5 can then be fitted, followed by 3.5mm stereo socket CON4. Then fit the four SIL headers used to make the interconnections between the *MFM* shield and the Arduino. As you can see from the photos, these mount on the top of the *MFM* shield PCB, with their pins soldered to the pads underneath.

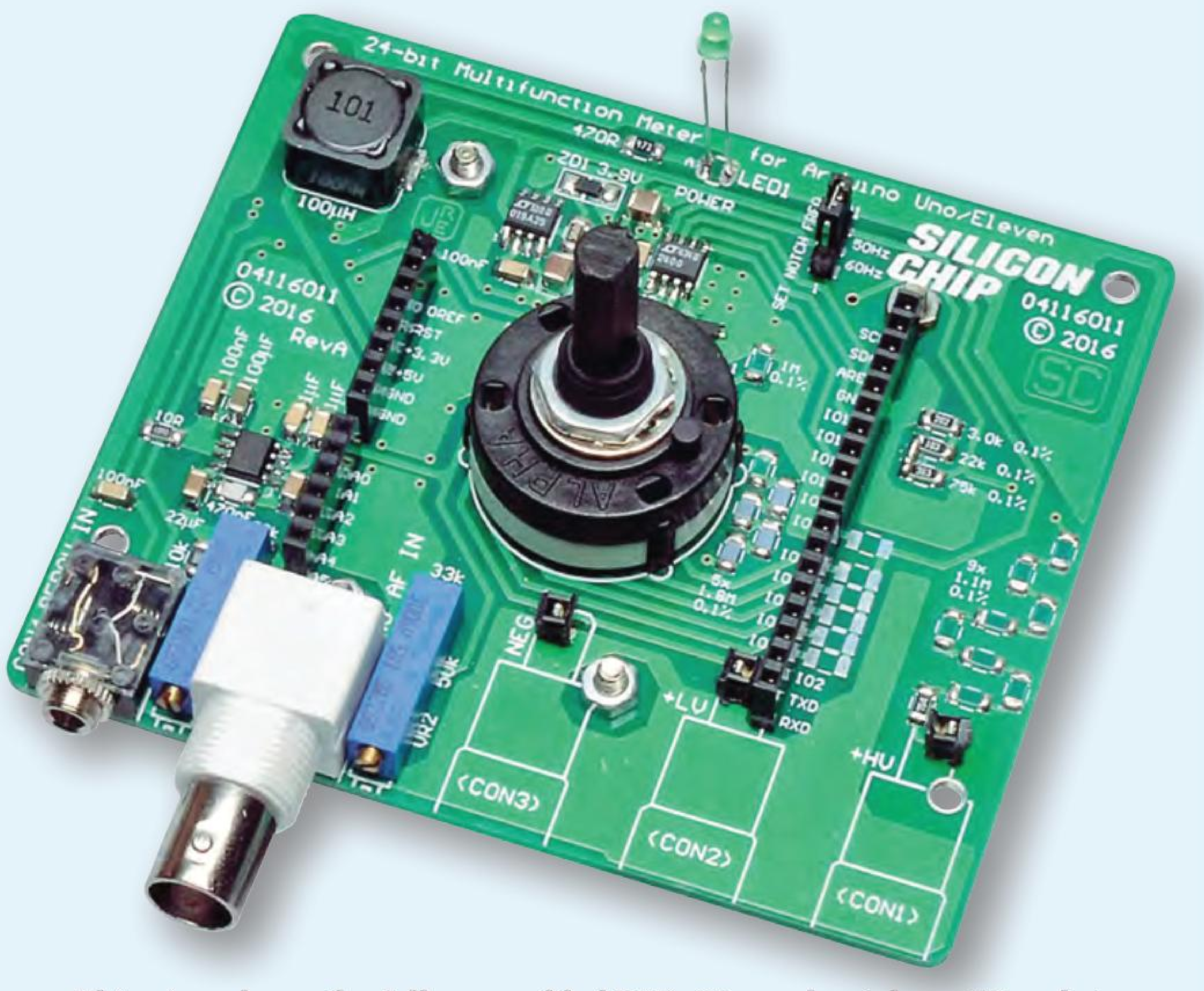
Take care to use the minimum solder necessary to make a reliable joint, as the main length of each pin needs to be free from solder, flux and dirt in order to make good contact with the matching clips in each Arduino SIL socket.

With the headers all in place, fit the 3-pin SIL header for JP1 at upper right. Then pass 20mm lengths of 0.75mm tinned copper through the three holes at lower-right on the main PCB, soldering them to the pad underneath. These will later be soldered to DC input connectors CON1-CON3. Alternatively, you can use cut-down IC socket pins as shown in the photo below, but soldered connections may be more reliable.

Rotary switch S1 can now go in, after first having its spindle cut to around 17mm long (remove any swarf with a small file or hobby knife). Make sure it's oriented correctly, with the plastic post on the right side, as shown in Fig.4, so the knob will go on the correct way around.



The *RF Head* PCB fits inside a metal diecast case measuring just 51 × 51 × 32mm. It's mounted on 12mm spacers, as shown in Fig.5.



This view shows the fully-assembled PCB. We used cut-down IC socket pins to accept the tinned copper wire leads from CON1-CON3.

The shield PCB can now be completed by fitting LED1. This is mounted at top/rear centre with its leads at their full length so that the underside of the LED's body is 24mm above the top of the PCB (use a cardboard spacer).

To finish the RF Head PCB, fit SMA input socket CON6 to the bottom edge of the PCB and 3.5mm socket CON7 at the top. The SMA socket is 'edge mounted', with the PCB passing through its side slots and its centre pin resting on the central rectangular pad on the top of the PCB. Solder this pin to that pad, then solder the earthy 'side bars' to the matching copper pads on both the top and bottom of the PCB.

Both of your *MFM* boards should now be complete and ready to be mounted in the two boxes. We will describe how to do that next, but **we recommend you go through the test procedure (to be described in Part 2) first, before mounting it in the box.**

Preparing the boxes

The drilling and cutting details for both boxes can be downloaded from the *EPE* website. There are 11 holes to drill in the main case, plus one rectangular cut-out, and seven holes in the *RF Head* case.

Note that the rectangular cut-out is sized to suit a USB type B plug, as required by the Arduino Uno or Duinotech Classic. You could get away with making a smaller cut-out for the micro-USB input on a Freetronics Eleven.

Once all the holes and cut-outs have been made, remove any burrs from the

Parts List

- 1 double-sided PCB, 96 × 83mm, code 04116011. Available from the *EPE PCB Service*
- 1 diecast aluminium box, 119 × 94 × 57mm
- 1 lid panel label, 103 × 84.5mm
- 1 Arduino Uno, Freetronics Eleven or Duinotech Uno module
- 1 USB cable to suit Arduino module
- 1 2-pole 6-position rotary switch, PCB mounting (S1)
- 1 instrument knob, 24mm diameter
- 1 100µH SMD RF inductor
- 1 3-pin SIL header with jumper shunt (JP1)
- 2 red panel-mount banana sockets, fully insulated (CON1-CON2)
- 1 black panel-mount banana socket, fully insulated (CON3)
- 1 3.5mm stereo switched jack socket (CON4)
- 1 PCB-mount BNC socket (CON5)
- 1 2kΩ multi-turn horizontal trimpot (VR1)
- 1 50kΩ multi-turn horizontal trimpot (VR2)
- 1 set Arduino male/female headers
- 4 M3 × 25mm tapped spacers
- 8 M3 × 6mm machine screws
- 4 4.5mm OD, 12mm-long untapped spacers
- 4 M3 × 20mm machine screws
- 4 M3 hex nuts
- 4 stick-on rubber feet
- 1 14-pin DIL socket (for CON1-3)

Semiconductors

- 1 LTC2400CS8#PBF 24-bit ADC, SOIC-8 (IC1)
- 1 AD8307ARZ logarithmic amplifier/detector, SOIC-8 (IC2)
- 1 LT1019ACS8-2.5#PBF precision 2.5V reference, SOIC-8 (REF1)
- 1 3.9V 1W zener diode, SC-109B (ZD1)
- 1 3mm green LED (LED1)
- 2 1N5711W-7-F Schottky diodes, SOD-123 (D1,D2)

Capacitors (all 1206 SMD)

- 1 100µF 6.3V X5R
- 2 22µF 10V X5R
- 2 10µF 16V X5R
- 2 1µF 16V X7R
- 4 100nF 16V X7R
- 1 470pF 100V C0G/NP0

Resistors (0.25W 1206 SMD)

- 1 750kΩ 0.1%
- 8 499kΩ 0.1%
- 4 100kΩ 0.1%
- 2 50kΩ 0.1%
- 1 39kΩ 1%
- 1 36kΩ 0.1%
- 1 33kΩ 1%
- 1 20kΩ 1%
- 1 10kΩ 1%
- 1 10kΩ 0.1%
- 1 2.0kΩ 0.1%
- 1 1.5kΩ 1%
- 1 470Ω 1%
- 1 10Ω 1%
- 1 5.6Ω 1%

RF Head (optional)

- 1 double-sided PCB, Available from the *EPE PCB Service,* coded 04116012, 42 × 41mm
- 1 AD8307ARZ logarithmic amplifier/detector, SOIC-8 package (IC3)
- 1 diecast aluminium box, 51 × 51 × 32mm
- 1 front panel label, 45.5 × 45.5mm
- 1 PCB edge-mount SMA socket (CON6)
- 1 3.5mm stereo switched jack socket (CON7)
- 1 2kΩ multi-turn vertical trimpot (VR3)
- 2 12mm × 4.5mm OD untapped spacers
- 2 M3 × 20mm machine screws
- 2 M3 hex nuts
- 1 3.5mm stereo jack to 3.5mm stereo jack cable, length to suit user requirements
- 4 stick-on rubber feet

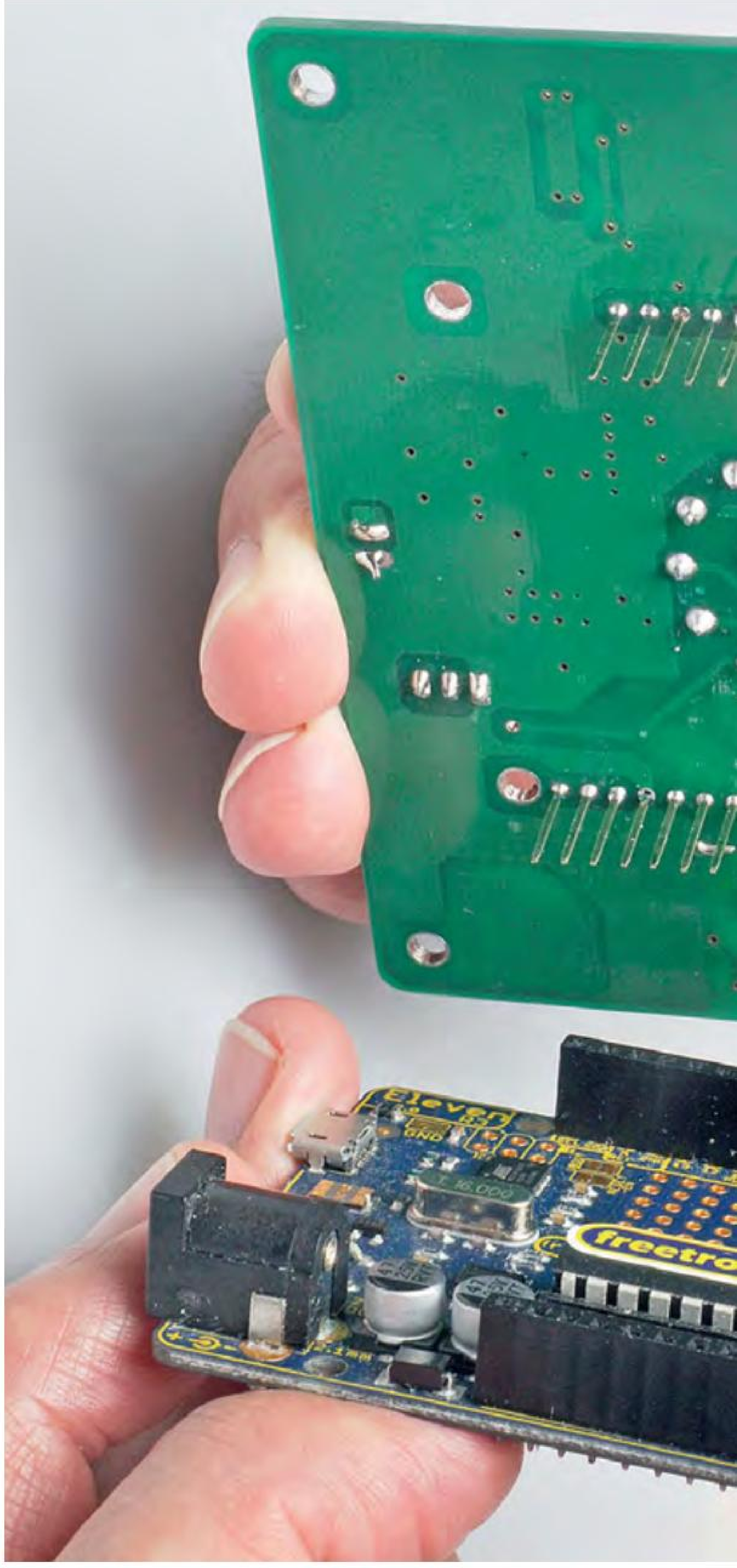
Capacitors (all 1206 SMD)

- 3 100nF 16V X7R
- 2 47nF 50V X7R

Resistors (0.25W, 1% 1206 SMD)

- 2 200kΩ
- 1 1.5kΩ
- 1 560Ω
- 1 4.7Ω

Reproduced by arrangement
with SILICON CHIP
magazine 2017.
www.siliconchip.com.au



The header pins on the back of the *MFM* shield PCB are plugged into matching headers on the Arduino PCB. The assembly is then secured using 12mm-long untapped spacers and M3 × 20mm machine screws and nuts (see Fig.5).

inner and outer edges with a large drill or needle file.

Box assembly

Fig.5 shows how the two PCBs are mounted. The procedure is as follows:

(1) Plug the *MFM* Shield PCB into the Arduino module, making sure they are properly aligned. Don't push both boards together as far as they'll go.

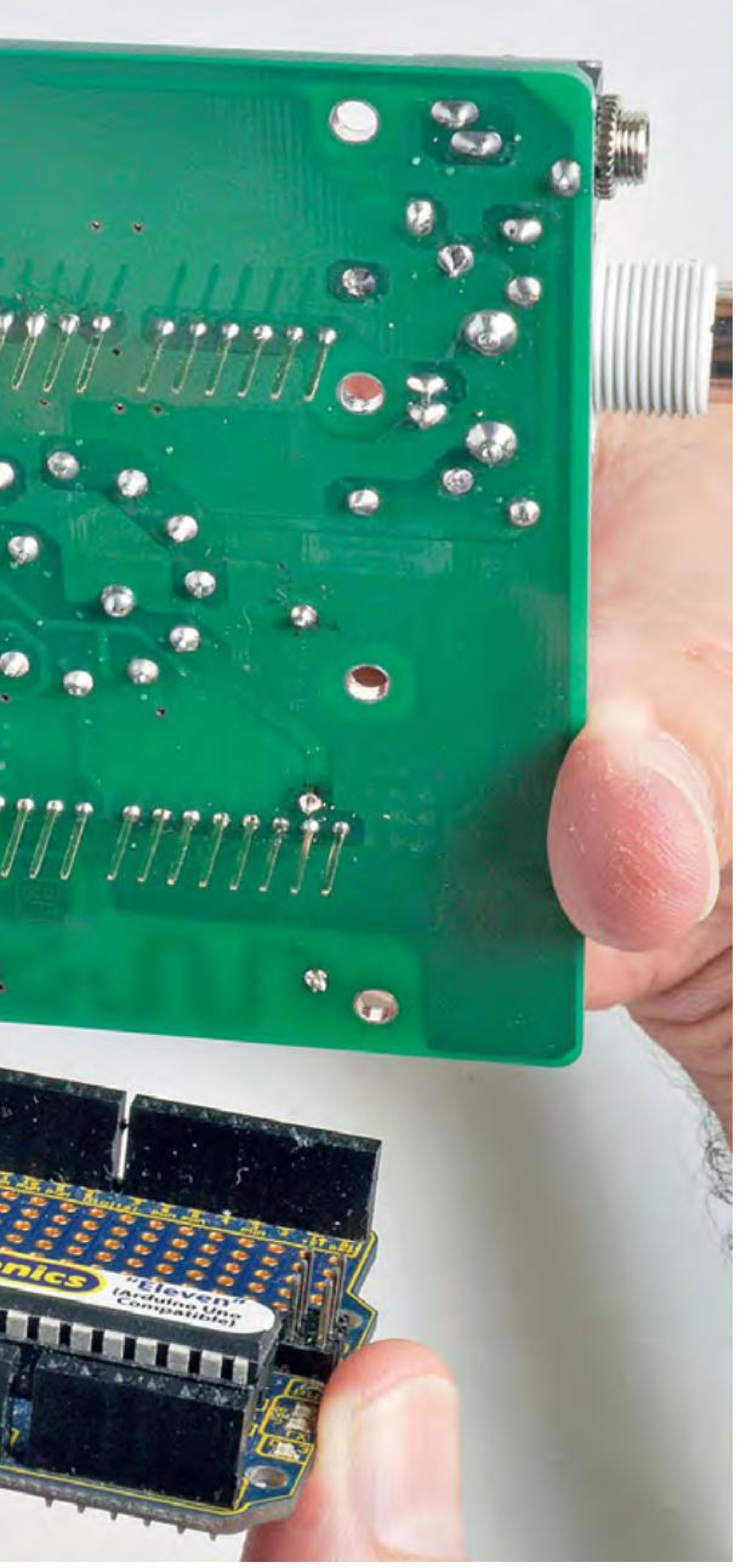
(2) Slip four 12mm long untapped spacers into the locations for the Arduino mounting screws between the two boards.

(3) Push M3 × 20mm machine screws up through the Arduino PCB and each spacer and fit M3 hex nuts on the top.

(4) Gradually tighten each screw and nut until the two PCBs are held together. **Note that you will need to file a small amount of metal off one 'flat' of the nut used on the mounting screw that is very close to the rear end of the 10-way SIL header (the one at upper right in Fig.4) so it doesn't interfere.**

(5) Fit four M3 × 25mm tapped spacers into the bottom of the case using M3 × 6mm screws. Don't tighten these screws up fully yet.

(6) Remove the nut and lockwasher from the front of BNC socket CON5.


"Eleven" (Arduino Uno Compatible)

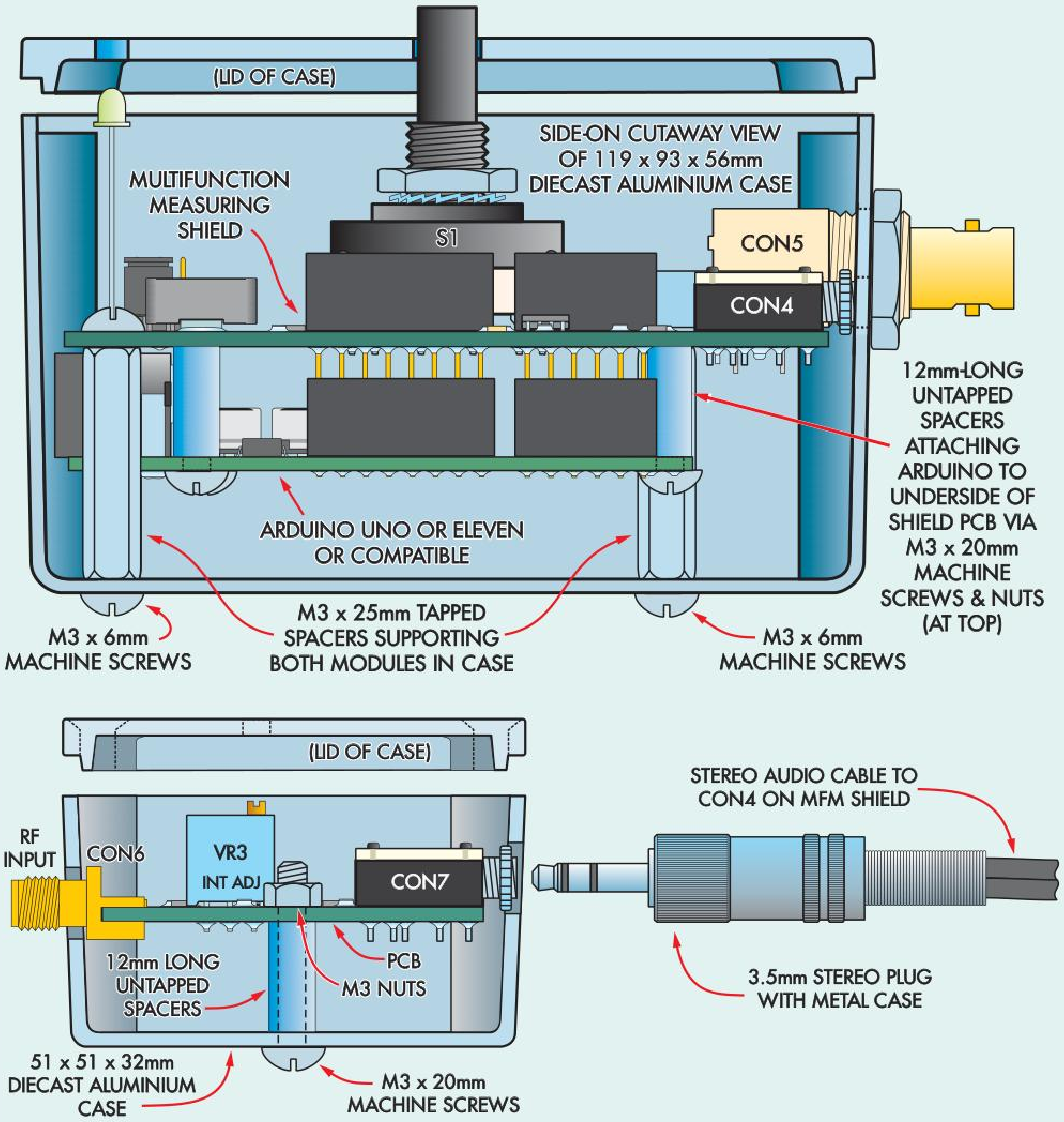

(LID OF CASE)
SIDE-ON CUTAWAY VIEW OF 119 x 93 x 56mm DIECAST ALUMINIUM CASE
MULTIFUNCTION MEASURING SHIELD
S1
CON5
CON4
12mm-LONG UNTAPPED SPACERS ATTACHING ARDUINO TO UNDERSIDE OF SHIELD PCB VIA M3 x 20mm MACHINE SCREWS & NUTS (AT TOP)
ARDUINO UNO OR ELEVEN OR COMPATIBLE
M3 x 6mm MACHINE SCREWS
M3 x 25mm TAPPED SPACERS SUPPORTING BOTH MODULES IN CASE
M3 x 6mm MACHINE SCREWS
(LID OF CASE)
STEREO AUDIO CABLE TO CON4 ON MFM SHIELD
RF INPUT
CON6
VR3
INT ADJ
CON7
12mm LONG UNTAPPED SPACERS
PCB
M3 NUTS
3.5mm STEREO PLUG WITH METAL CASE
51 x 51 x 32mm DIECAST ALUMINIUM CASE
M3 x 20mm MACHINE SCREWS

Fig.5: here's how the PCB assemblies are mounted inside the diecast cases. The Arduino board is mounted on the *MFM* shield PCB using four 12mm untapped spacers and secured with machine screws and nuts. The entire assembly is then mounted on the bottom of the case on M3 × 25mm tapped spacers. The *RF Head* PCB is secured inside its case on two 12mm-long untapped spacers.

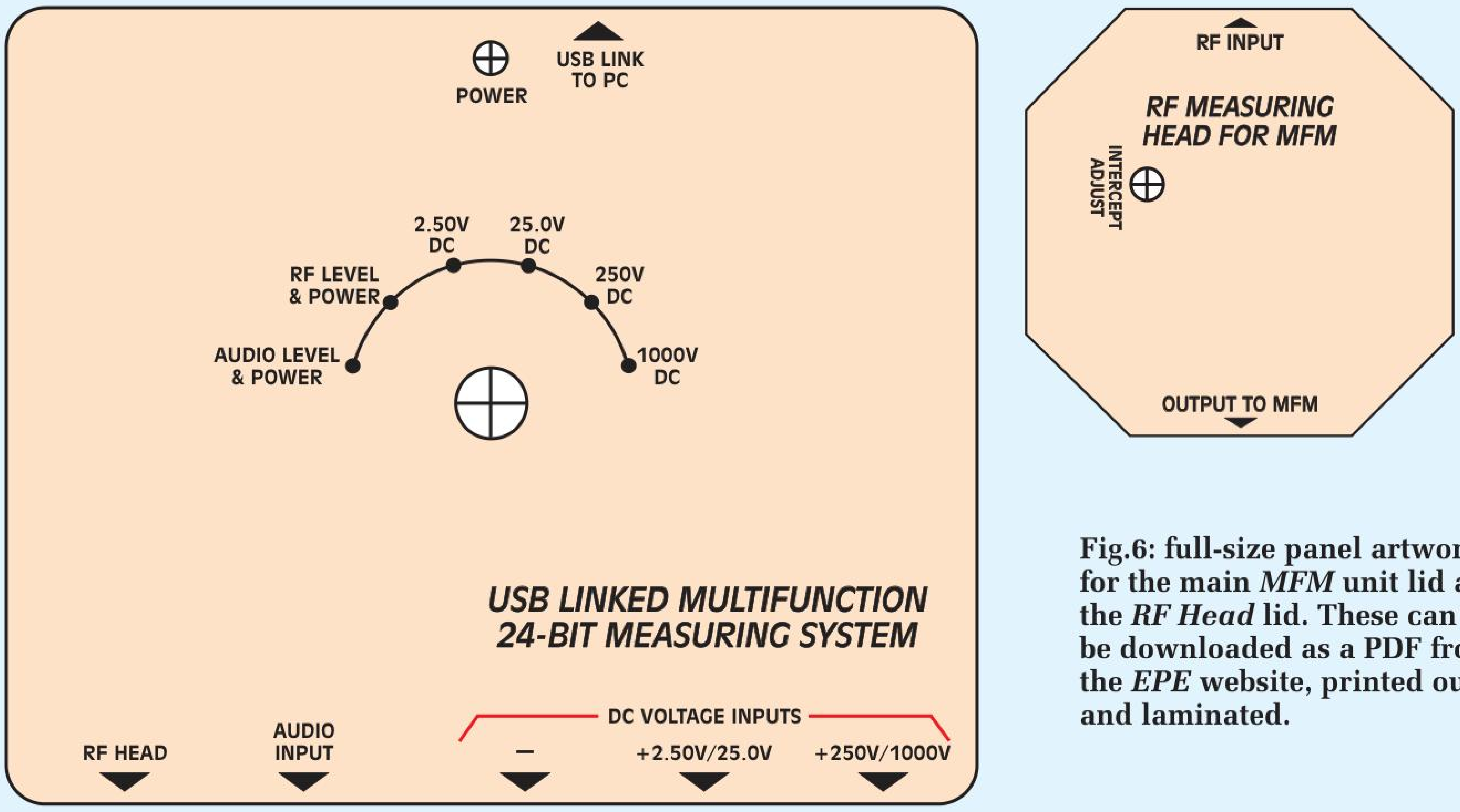
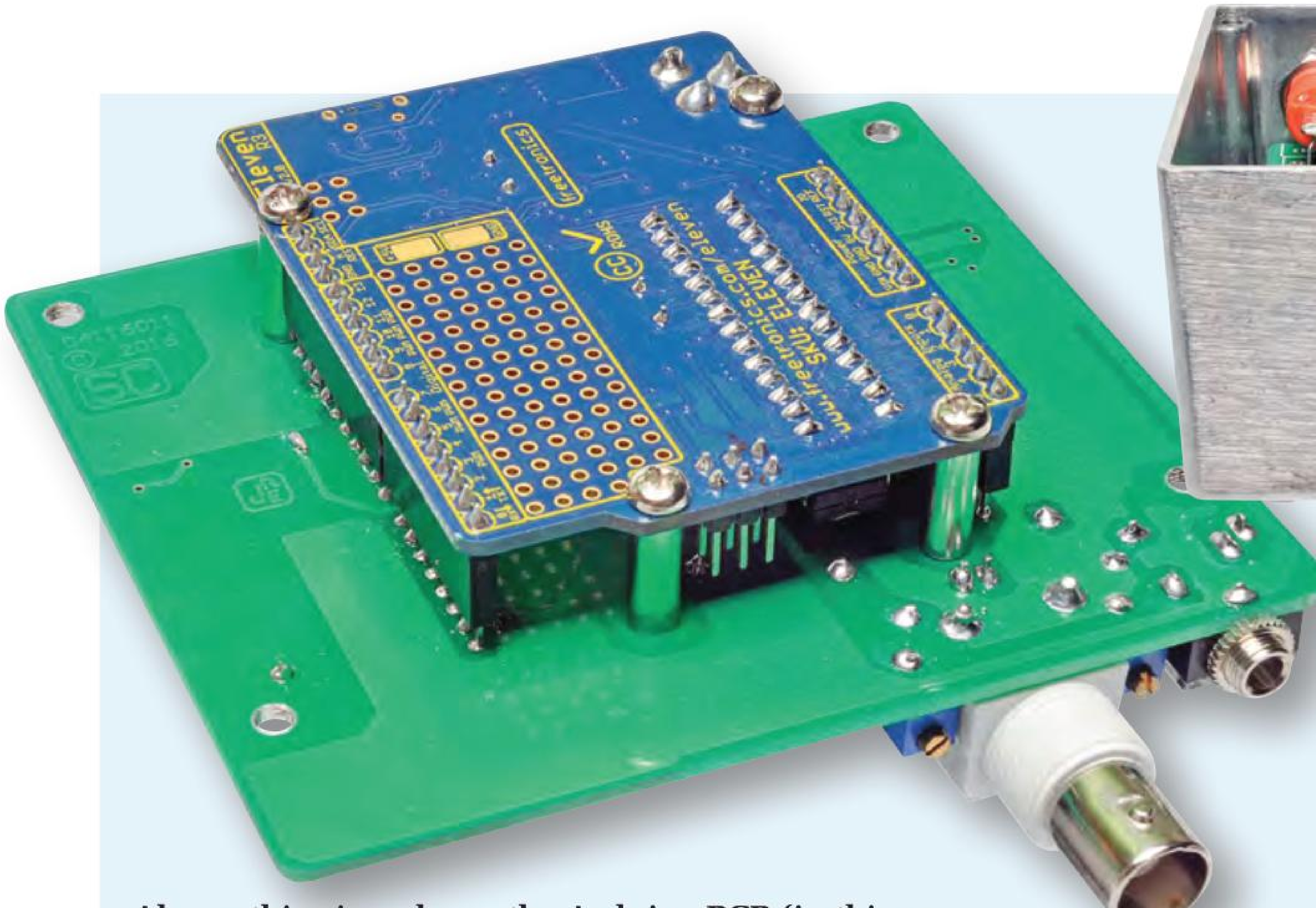
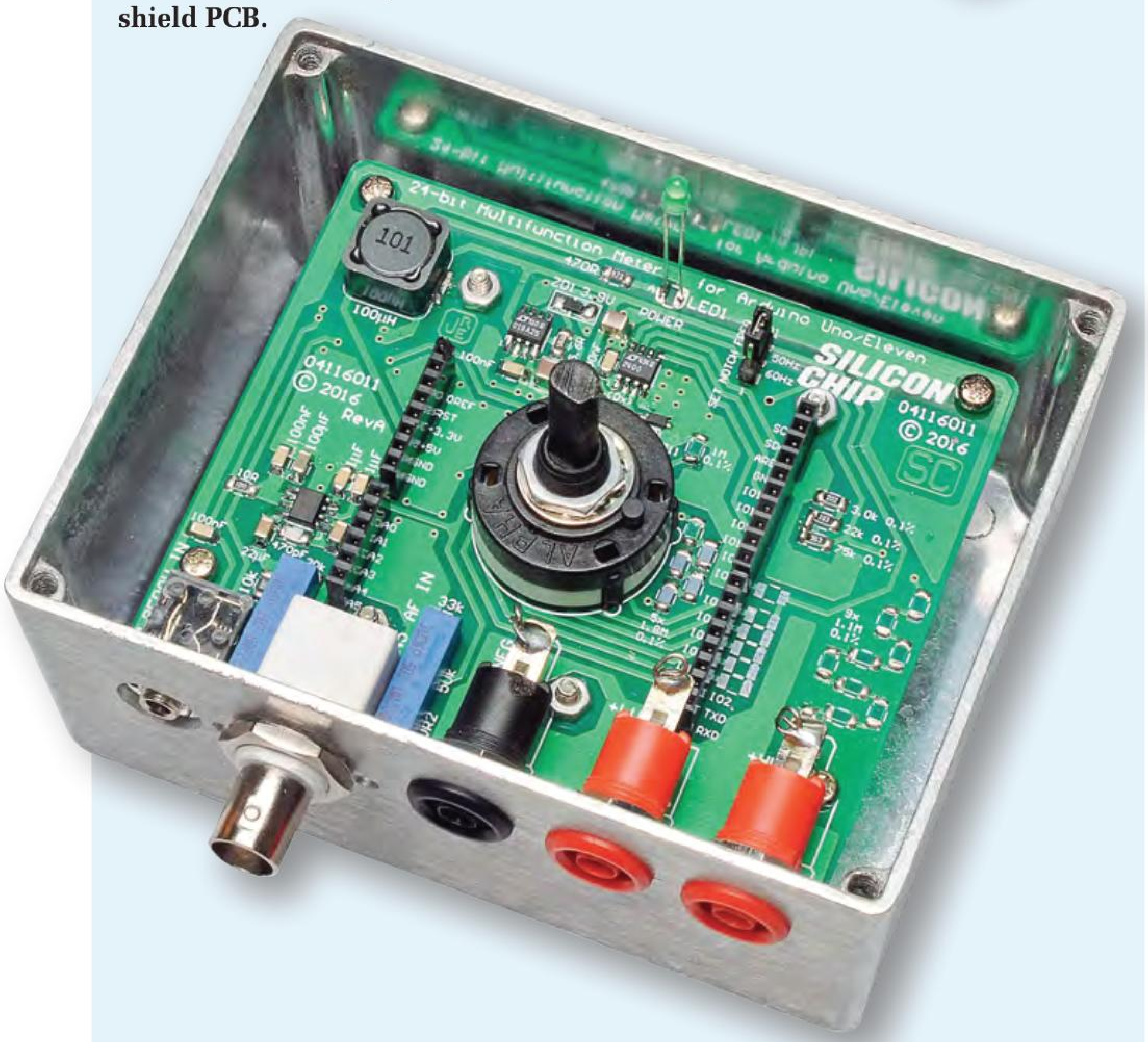

POWER
USB LINK TO PC
2.50V DC
25.0V DC
RF LEVEL & POWER
250V DC
AUDIO LEVEL & POWER
1000V DC
USB LINKED MULTIFUNCTION 24-BIT MEASURING SYSTEM
DC VOLTAGE INPUTS
RF HEAD
AUDIO INPUT
–
+2.50V/25.0V
+250V/1000V
RF INPUT
RF MEASURING HEAD FOR MFM
INTERCEPT ADJUST
OUTPUT TO MFM

Fig.6: full-size panel artwork for the main *MFM* unit lid and the *RF Head* lid. These can also be downloaded as a PDF from the *EPE* website, printed out and laminated.



Above: this view shows the Arduino PCB (in this case, a Freetronics Eleven) mounted on the rear of the *MFM* shield PCB.

The rear panel has a cut-out to access the USB socket on the Arduino module. Note that this cut-out can be made smaller than shown if the module is fitted with a micro-USB socket.



The PCB assembly is installed in the case by first angling the BNC socket down through its hole, then forcing the rear of the assembly down into the case. The three banana sockets are then fitted and wired to the shield PCB.

(7) Insert BNC socket CON5 through its corresponding hole in the front of the box, then force the PCB assembly down into the case until it is resting on top of the four 25mm spacers.

(8) Attach the *MFM* shield board to these spacers using M3 × 6mm screws, then tighten the corresponding screws in the bottom of the case.

(9) Screw the lockwasher and nut back onto the ferrule of BNC socket CON5.

(10) Remove the nuts from the three banana sockets for CON1-CON3, push them through the 12mm holes in the front of the box and slip the nuts back on. Make sure the black socket (CON3) is closest to BNC socket CON5.

(11) Rotate the banana sockets so that their tabs are horizontal and do the nuts up tight.

(12) Bend the previously soldered lengths of tinned copper wire so they pass through the corresponding banana socket holes, then solder them in place (or push tinned copper wire leads into cut-down IC sockets and then solder these to CON1-CON3).

(13) Attach the label to the lid.

(14) Drop the lid in place, ensuring that LED1 passes through its 3mm hole, then screw the lid down and attach the knob.

RF Head assembly

Use the following steps to assemble the *RF Head*:

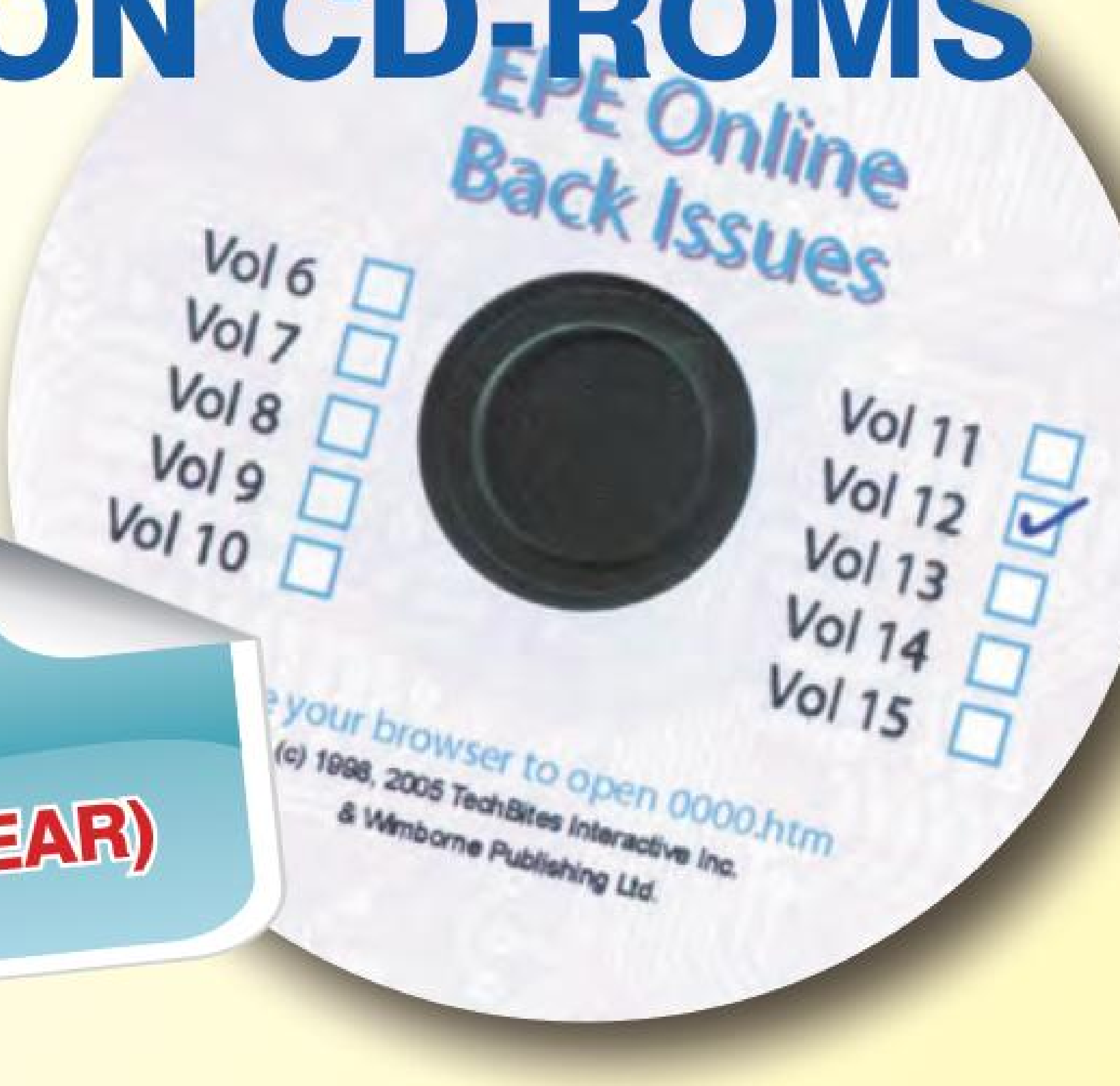
1) Push M3 × 20mm machine screws up through the two holes in the bottom of the box, then slip a 12mm-long untapped spacer over each.
2) Insert CON6 through the larger hole in the side of the box, then lower the PCB into place and slide it back so that CON7's ferrule lines up with its smaller hole opposite.
3) Attach the board using two M3 hex nuts. Do these up nice and tight.
4) Attach the label to the lid.
5) Secure the lid in place, making sure that the hole to allow trimpot VR3 to be adjusted is positioned above the trimpot's screw.

Next month

Your *Multifunction Meter* hardware is now complete and you're ready to tackle the remaining steps such as installing the firmware and software, calibration and finally putting the instrument to use. These topics will be covered in Part 2 next month.

STORE YOUR BACK ISSUES ON CD-ROMS

Order on-line from
www.epemag.com (go to the UK store)
or by phone, fax, email or post


EPE Online
Back Issues
Vol 6
Vol 7
Vol 8
Vol 9
Vol 10
Vol 11
Vol 12
Vol 13
Vol 14
Vol 15
Use your browser to open 0000.htm
(c) 1998, 2005 TechBites Interactive Inc.
& Wimborne Publishing Ltd.

ONLY
£16.45
(£29.95 FOR 5 YEAR)
each including VAT and p&p

VOL 1: BACK ISSUES – January 1999 to June 1999
Plus some bonus material from Nov and Dec 1998
VOL 2: BACK ISSUES – July 1999 to December 1999
VOL 3: BACK ISSUES – January 2000 to June 2000
VOL 4: BACK ISSUES – July 2000 to December 2000
VOL 5: BACK ISSUES – January 2001 to June 2001
VOL 6: BACK ISSUES – July 2001 to December 2001
VOL 7: BACK ISSUES – January 2002 to June 2002
VOL 8: BACK ISSUES – July 2002 to December 2002
VOL 9: BACK ISSUES – January 2003 to June 2003
VOL 10: BACK ISSUES – July 2003 to December 2003
VOL 11: BACK ISSUES – January 2004 to June 2004
VOL 12: BACK ISSUES – July 2004 to December 2004
VOL 13: BACK ISSUES – January 2005 to June 2005
VOL 14: BACK ISSUES – July 2005 to December 2005
VOL 15: BACK ISSUES – January 2006 to June 2006
VOL 16: BACK ISSUES – July 2006 to December 2006
VOL 17: BACK ISSUES – January 2007 to June 2007
VOL 18: BACK ISSUES – July 2007 to December 2007
VOL 19: BACK ISSUES – January 2008 to June 2008
VOL 20: BACK ISSUES – July 2008 to December 2008
VOL 21: BACK ISSUES – January 2009 to June 2009
VOL 22: BACK ISSUES – July 2009 to December 2009
VOL 23: BACK ISSUES – January 2010 to June 2010
VOL 24: BACK ISSUES – July 2010 to December 2010
VOL 25: BACK ISSUES – January 2011 to June 2011
VOL 26: BACK ISSUES – July 2011 to December 2011
VOL 27: BACK ISSUES – January 2012 to June 2012
VOL 28: BACK ISSUES – July 2012 to December 2012
VOL 29: BACK ISSUES – January 2013 to June 2013
VOL 30: BACK ISSUES – July 2013 to December 2013
VOL 31: BACK ISSUES – January 2014 to June 2014
VOL 32: BACK ISSUES – July 2014 to December 2014
VOL 33: BACK ISSUES – January 2015 to June 2015

NEW Vol.34

VOL 34: BACK ISSUES –
July 2015 to December 2015

FIVE YEAR DVD/CD-ROMs NOW AVAILABLE

FIVE YEAR CD/DVD-ROMs

No.1 – Jan '03 to Dec '07
No.2 – Jan '04 to Dec '08
No.3 – Jan '05 to Dec '09
No.4 – Jan '06 to Dec '10
No.5 – Jan '07 to Dec '11
No.6 – Jan '08 to Dec '12
No.7 – Jan '09 to Dec '13
No.8 – Jan '10 to Dec '14
No.9 – Jan '11 to Dec '15

NEW No.9

NOTE: These DVD/CD-ROMs are suitable for use on any PC with a DVD/CD-ROM drive. They require Adobe Acrobat Reader (available free from the Internet – **www.adobe.com/acrobat**)

WHAT IS INCLUDED

All volumes include the *EPE Online* content of every listed issue. **Please note that we are unable to answer technical queries or provide data on articles that are more than five years old. Please also ensure that all components are still available before commencing construction of a project from a back issue.**

BACK ISSUES DVD/CD-ROM ORDER FORM

Please send me the following Back Issue DVD/CD-ROMs.

Volume Numbers:. . . . .
. . . .

Price £16.45 each, £29.95 for Five Year DVD/CD-ROMs – includes postage to anywhere in the world.

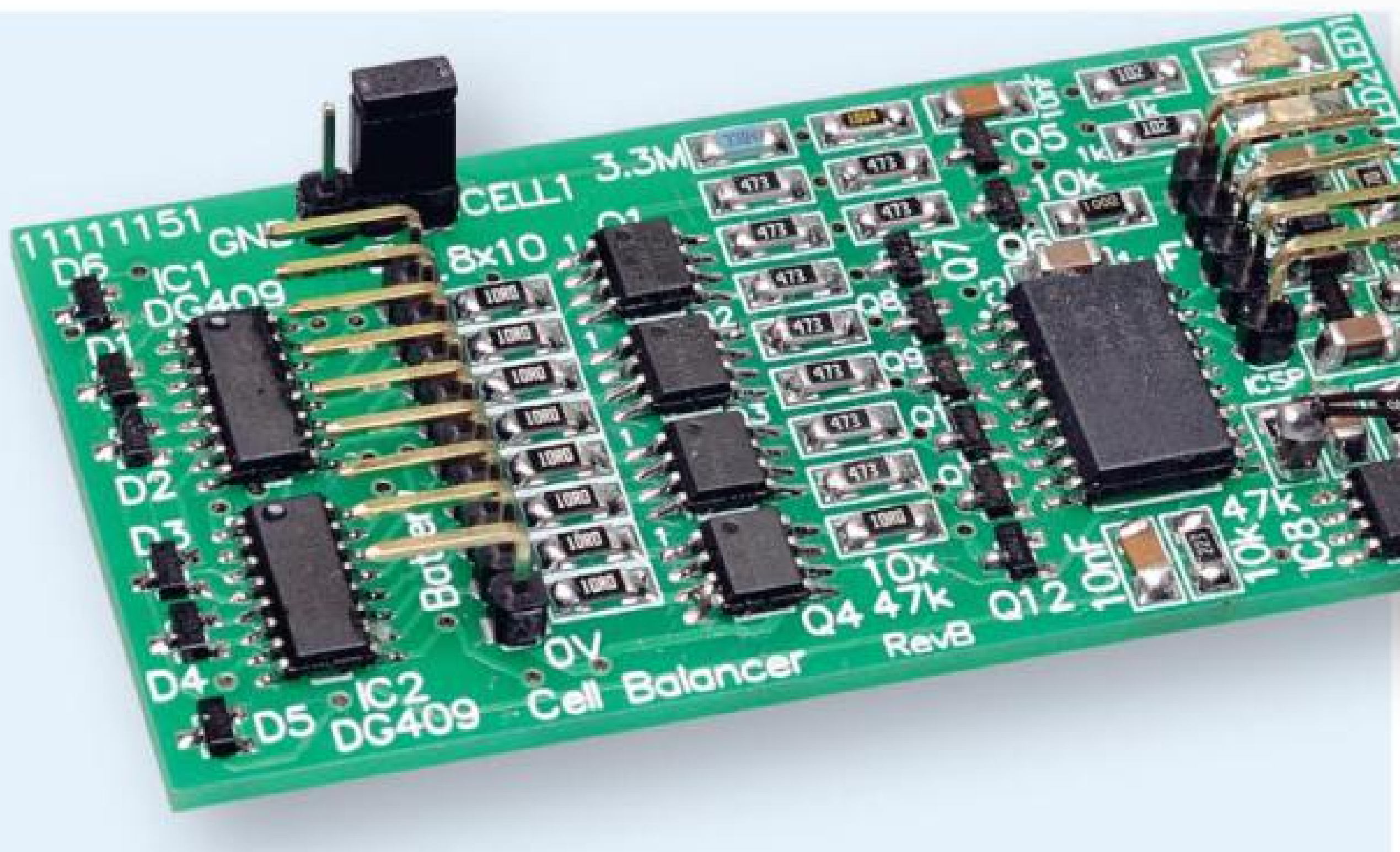
Name . . . .
. . . .
Address . . . .
. . . .
. . . .
Post Code. . . . .
☐ I enclose cheque/P.O./bank draft to the value of £ . . . .
☐ please charge my Visa/Mastercard £ . . . .
Card No. . . . .
Card Security Code . . . . (The last 3 digits on or just under the signature strip)
Valid From . . . . Expiry Date . . . .

SEND TO: **Everyday Practical Electronics,**
Wimborne Publishing Ltd., 113 Lynwood Drive, Merley,
Wimborne, Dorset BH21 1UU.

Tel: 01202 880299. Fax: 01202 843233.
E-mail: orders@epemag.wimborne.co.uk

Payments must be by card or in £ Sterling – cheque or bank draft drawn on a UK bank.
Normally posted within seven days of receipt of order.

Battery Pack Cell Balancer



Many multi-purpose chargers can handle lithium-ion, lithium-polymer or LiFePO_4 batteries. But they may not balance the charge between individual cells and this can lead to incomplete charging and premature failure. This small device solves this by providing the balancing function separately. It can also be used with Nicad and NiMH packs for a longer life-span and is suitable for use with the *MPPT Solar Lighting Charger/Controller* published in the previous two issues.

By Nicholas Vinen

TRADITIONAL BATTERY chargers treat a battery as a device having two terminals, delivering current until the battery voltage reaches a certain level. The termination voltage is the fully-charged cell voltage multiplied by the number of cells and the assumption is that when the battery reaches this voltage, each cell is fully charged. However, this relies on the cells being identical.

Similarly, the battery is determined to be flat when the overall voltage reaches a level indicating that each cell is fully discharged. But if one cell starts out with a lesser charge or discharges faster for some reason, it could be over-discharged before this threshold is reached. This could damage the cell, leading to lower capacity and a shorter battery-pack life.

It's quite typical for a battery-pack to fail because the internal resistance of just one cell has gone high. The charge and discharge current must flow through all cells, so once one cell can no longer pass enough current, the whole battery is useless. Similarly, if one cell's voltage is especially low (or perhaps even negative), the fully charged battery voltage may be insufficient, even though the rest of the cells are healthy.

So, for the longest battery life you need to ensure that all cells are charged and discharged equally. Even with a brand new battery, cell capacity may vary slightly (by one or two percent, say) but over time, this can worsen. This effect is greater with lithium-based cells than other types, which is why it's important to ensure they are properly balanced during charging.

Consider a 4-cell LiPo battery with one cell that has 2% lower capacity than the others. All cells start out fully discharged at 3V, ie, the battery is at 12V. It is then charged to 16.8V, which we would expect to yield 4.2V per cell. However, since the lower capacity cell will charge faster, it may have reached 4.3V while the other cells are all at 4.166V. 4.3V + 4.166V x 3 = 16.8V, so the charger can't tell the difference.

This cell has now been overcharged and this could lower its capacity further, to say 3% below the rest. Despite its lower capacity, it has a higher charge state than the other cells, so after discharge the voltages may be equal again. But eventually its capacity could drop so much that it also starts discharging further than the other cells each cycle, accelerating the damage.

Features and Specifications

- Balances Li-ion, LiPo or LiFePO$_4$ batteries with 2-8 cells
- Can also balance NiMH or Nicad packs with 4-8 cells
- Fully charged battery voltage of up to 33.6V (8 x 4.2V)
- Suitable for use with chargers up to 10A
- Will work with chargers >10A, but not as effectively
- Cell balancing shunt current: ~200mA
- Very low quiescent current: <25μA
- Compact PCB can be mounted next to battery pack
- Works with virtually any non-balancing charger
- Plugs straight into typical battery balance connectors
- No external power required
- Automatically detects number of cells
- Detection of charging by cell voltage or via external signal
- Adjustable cell voltage balance start threshold via resistor
- LEDs indicate balance status

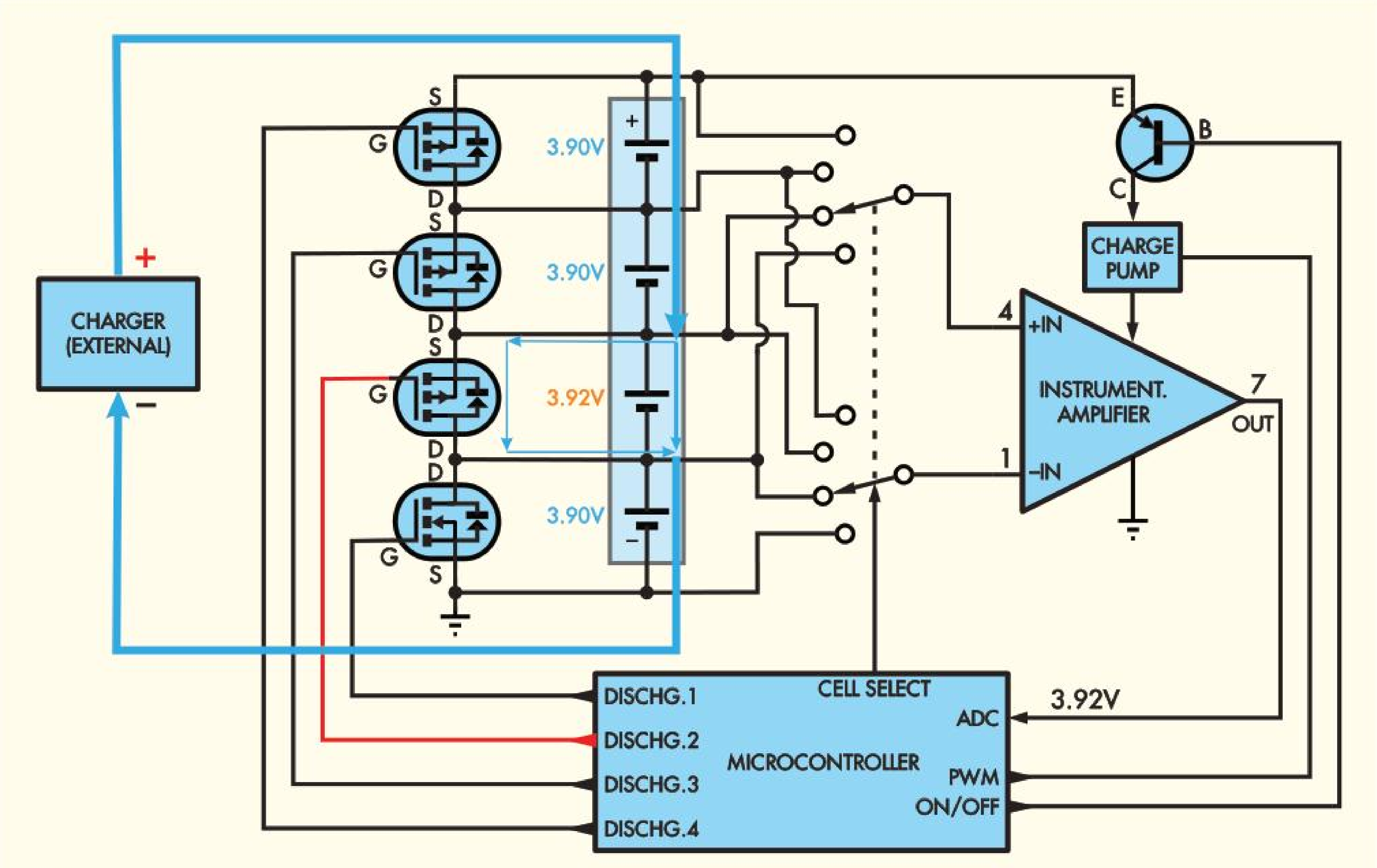


Fig.1: a simplified circuit showing the general principle of cell balancer operation. We're showing four cells, but our balancer will work with up to eight. MOSFETs are connected across each cell, to divert some of the charge current if that cell's voltage rises higher than the others. Analogue switching, driven by a microcontroller, allows each cell to be connected across the inputs of an instrumentation amplifier, so the micro can measure that cell's voltage. A charge pump is used to provide sufficient voltage for the instrumentation amplifier to operate, while a transistor allows its supply to be switched off when it isn't being used.

The simple solution is to monitor the voltage of each cell during charging and shunt current around those cells which have a higher voltage than the others. This reduces the charge delivered to lower capacity cells, so they all reach the correct charge termination voltage simultaneously. This not only prevents weak cells from being overcharged, but also stops strong cells from being under-charged.

Arguably, it's a good idea to monitor and balance cell voltages during discharge too; however, if balancing occurs during charging, this should hopefully keep the cells healthy and they will discharge at a more or less equal rate. Serious imbalances normally take multiple charge/discharge cycles to build up, so regular cell balancing during charging is thought to be sufficient.

However, should you wish to balance a battery pack while it's being discharged, our unit can do that too. It can be constantly active, drawing very little current until an imbalance is detected, at which point it 'wakes up' and attempts to rectify it.

Our cell balancer

The concept of a cell balancer is quite simple. It periodically checks the voltage of all cells. If one cell has a significantly higher voltage than the others, some of the charge current is shunted around it, or if the battery is not currently being charged, it is discharged slightly. This reduces its voltage back in line with the others. This process is continuous, so as soon as any cell's voltage starts rising above the others, it is brought back in line.

Block diagram

The basic principle is shown in the simplified circuit of Fig.1, drawn with a 4-cell battery. Blue arrows show the flow of current from the charger through the battery. The second cell has a higher voltage than the others, so the microcontroller enables the corresponding MOSFET to divert some of the charge current around it.

There are some complications to this approach. Cell voltages will need to be measured accurately so that small imbalances can be detected before they become significant. Ideally, inter-cell error should be around 10mV or less.

This will prevent unnecessary shunting/discharging of the cells due to measurement error. In the worst case, if there is a bias in the way the balancer measures cell voltages, it could actually imbalance an already balanced pack!

Also, if the balancer is to be left connected to the battery pack (which, in fixed installations, it would be), it needs to have negligible drain when the battery is not being charged or balanced. Ideally, it should be able to detect when charging is occurring and switch off for the rest of the time.

It also needs to be able to shunt a sufficiently large percentage of the charge current to be able to 'keep up' with the rate at which cell imbalance can occur, without this resulting in excessive dissipation which could cause undesired heating of the balancer or the battery.

It should also ideally suit a wide range of battery types, from two cells or more and including all the different chemistries that may require balancing.

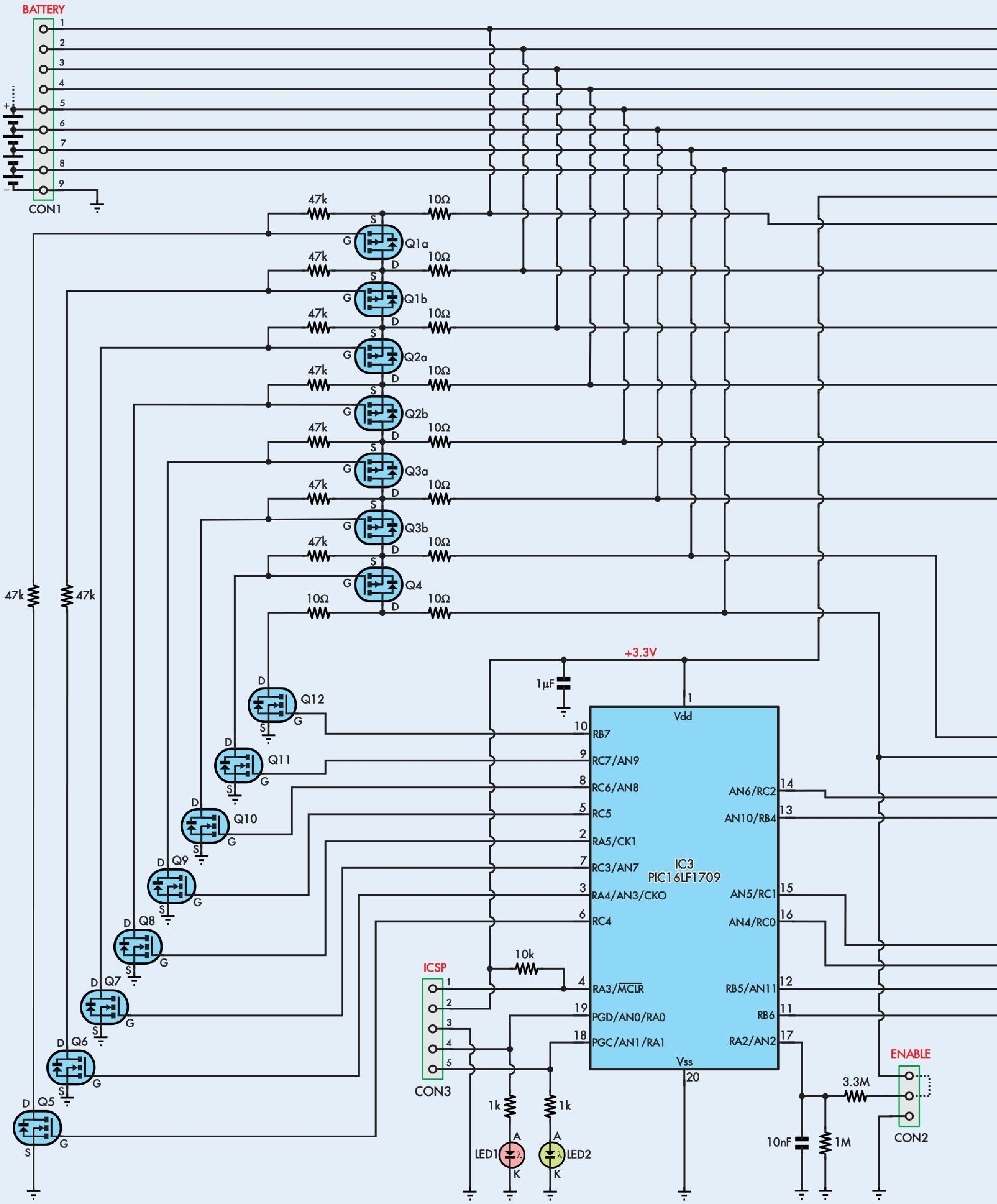
In order to accurately assess the difference in cell voltages, we've avoided using a voltage divider. If we had simply connected each cell to a micro's ADC inputs with its own divider, it would be difficult to assure cell-to-cell accuracy. And if we used dividers after some sort of analogue switching arrangement, they would have to be very accurate to keep the common-mode rejection ratio (CMRR) high enough.

Independent cell measurement

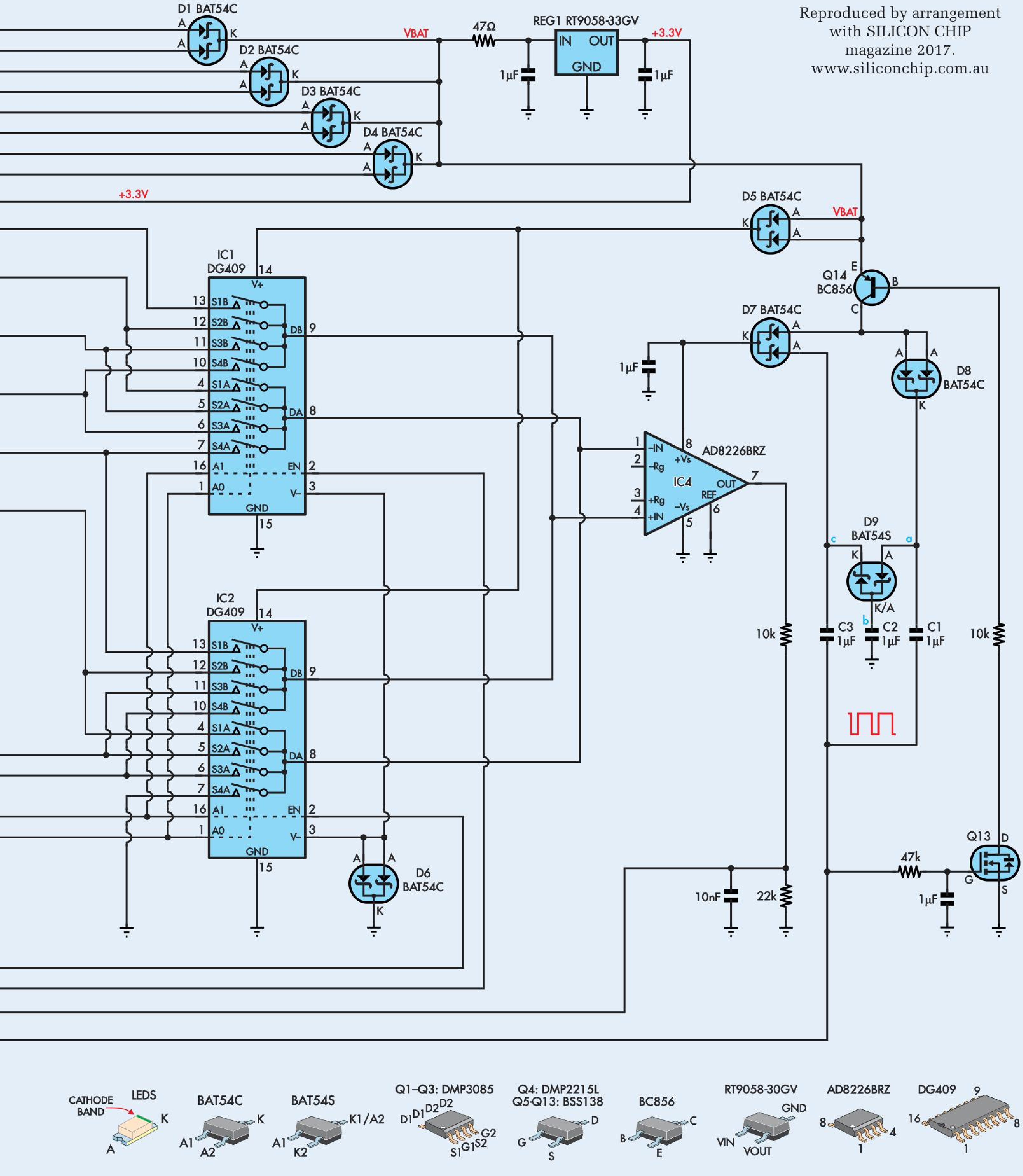
Instead, we are using analogue switches to connect one cell at a time to an instrumentation amplifier. This is effectively a differential op amp with a very high input impedance and a very high CMRR. These both contribute to providing very good differential voltage sensing accuracy. Its output is the voltage of the selected cell and this is then fed to the ADC input of a microcontroller.

The micro we have chosen is a PIC16LF1709, running at 3.3V. This has a 10-bit ADC which is sufficient to sense cell voltages with a resolution of less than 5mV, or even better with averaging. It's also capable of an ultra-low-power sleep mode, to minimise current drain when balancing is not occurring. To this end, it has been teamed up with an ultra-low quiescent current regulator and it can switch off power to the instrumentation amplifier when it isn't being used.

Current is shunted around a cell during charging, or the cell is partially discharged, by switching on a MOSFET connected across the cell with a pair of current-limiting resistors. These MOSFETs are controlled by individual output pins on the microcontroller.


BATTERY
1
2
3
4
5
6
7
8
9
+
–
CON1
47k
10Ω
S
G
Q1a
D
Q1b
Q2a
Q2b
Q3a
Q3b
Q4
47k
47k
+3.3V
1µF
Q12
Q11
Q10
Q9
Q8
Q7
Q6
Q5
IC3
PIC16LF1709
Vdd
1
10 RB7
9 RC7/AN9
8 RC6/AN8
5 RC5
2 RA5/CK1
7 RC3/AN7
3 RA4/AN3/CKO
6 RC4
4 RA3/MCLR
19 PGD/AN0/RA0
18 PGC/AN1/RA1
Vss
20
AN6/RC2 14
AN10/RB4 13
AN5/RC1 15
AN4/RC0 16
RB5/AN11 12
RB6 11
RA2/AN2 17
10k
ICSP
CON3
1k
1k
A
K
LED1
LED2
ENABLE
CON2
3.3M
10nF
1M

BATTERY CELL BALANCER


D1 BAT54C
D2 BAT54C
D3 BAT54C
D4 BAT54C
A
K
VBAT
47Ω
REG1 RT9058-33GV
IN
OUT
GND
+3.3V
1µF
+3.3V
D5 BAT54C
Q14
BC856
E
B
C
D7 BAT54C
D8
BAT54C
IC1
DG409
14
V+
S1B
S2B
S3B
S4B
S1A
S2A
S3A
S4A
A1
A0
DB
DA
EN
V–
GND
15
13
12
11
10
4
5
6
7
16
1
9
8
2
3
AD8226BRZ
IC4
–IN
–Rg
+Rg
+IN
+Vs
–Vs
OUT
REF
D9
BAT54S
K/A
c
a
b
C3
1µF
C2
1µF
C1
1µF
10k
IC2
DG409
D6
BAT54C
Q13
D
G
S
47k
10nF
22k
CATHODE BAND
LEDS
BAT54C
BAT54S
A1
A2
K1/A2
K2
Q1–Q3: DMP3085
D1
D2
G1
G2
S1
S2
Q4: DMP2215L
Q5-Q13: BSS138
BC856
RT9058-30GV
VIN
VOUT
AD8226BRZ
DG409

Reproduced by arrangement
with SILICON CHIP
magazine 2017.
www.siliconchip.com.au

Fig.2: the complete *Cell Balancer* circuit. Cell voltages at CON1 are connected to instrumentation amplifier IC4 by high-voltage analogue switches IC1 and IC2, then to microcontroller IC3's AN11 analogue input. IC3 can then switch on one of MOSFETs Q5-Q11, which in turn activate MOSFETs Q1a-Q3b or Q4 to shunt current around or discharge the cell with the highest voltage. The bottom-most cell is shunted directly by MOSFET Q12. IC3's pin 11 output drives a charge pump to boost IC4's supply so it can operate over the entire battery voltage range.

Parts List

1 double-sided PCB, available from the *EPE PCB Service*, coded 11111151, 69 × 35.5mm
1 3-way to 9-way pin header, 2.54mm pitch, straight or right angle to suit battery pack (CON1)
1 3-way pin header, 2.54mm pitch, with optional jumper shunt (CON2)
1 5-way pin header, 2.54mm pitch, straight or right angle (CON3, optional, for ICSP)
1 100mm length of heatshrink tubing, 50mm diameter (optional)

Semiconductors
2 DG409DY quad high-voltage CMOS switches, SOIC-16 (IC1,IC2)
1 PIC16LF1709-I/SO 8-bit microcontroller programmed with 1111115A.hex, SOIC-20 (IC3)
1 AD8226BRZ single supply instrumentation amplifier, SOIC-8 (IC4)
1 RT9058-33GV 3.3V (36V in) 100mA low-dropout, low-I_Q regulator, SOT-23 (REG1)
1 high-brightness red LED, SMD 3216/1206 (LED1)
1 high-brightness green LED, SMD 3216/1206 (LED2)
3 DMP3085 dual 30V P-channel MOSFETs, SOIC-8 (Q1-Q3)
1 DMP2215 20V P-channel MOSFET, SOT-23 (Q4)
9 BSS138 logic level N-channel MOSFETs, SOT-23 (Q5-Q13)
1 BC856 PNP transistor, SOT-23 (Q14)
8 BAT54CFILM dual 40V Schottky diodes, SOT-23 (D1-D8)
1 BAT54SFILM dual 40V Schottky diode, SOT-23 (D9)

Capacitors (SMD 3216/1206, X5R/X7R)
8 1µF 50V
2 10nF 50V

Resistors (SMD 3216/1206, 1%, ¼W)
1 3.3MΩ*
1 1MΩ
10 47kΩ
1 22kΩ
3 10kΩ
2 1kΩ
1 47Ω
9 10Ω 0.5W**

* change to set balance start voltage threshold
** 4.7Ω 0.5W preferred for use with NiMH/Nicad

Circuit description

The full circuit of the cell balancer is shown in Fig.2. The battery balance connector is usually a 2.54mm-pitch JST type, which plugs into CON1 with the negative-most terminal to pin 9, as shown. Between two and eight cells are connected and with fewer than eight cells, some pins will not be connected.

The terminals of CON1 are wired directly to the inputs of two dual 4-to-1 multiplexer ICs, IC1 and IC2. These DG409s will tolerate up to 44V and have a maximum on-resistance of 100Ω. They are wired so that, depending on the state of their control input pins (A0, A1 and EN), one cell at a time can be connected to the inverting and non-inverting inputs of instrumentation amplifier IC4 (pins 1 and 4).

For example, if A0 and A1 are low (0V) and the enable pin of IC1 is high, pin 1 of CON1 is connected to pin 4 of IC4 while pin 2 of CON1 is connected to pin 1 of IC4. Therefore, the voltage across the top-most cell of the battery (assuming it has eight) appears across IC4's inputs. IC4 is configured for unity gain, with no resistor between pins 2 and 3. Thus, the difference between the voltage at either end of the selected cell appears at output pin 7.

This is fed to analogue input AN11 (pin 12) of the PIC16LF1709 microcontroller via a 10kΩ/22kΩ resistive divider, with a 10nF capacitor connected across the bottom leg to act as a noise filter. The divider ensures that even with a fully-charged lithium-ion or lithium polymer battery, with a cell voltage of up to say 4.3V, no more than 2.96V will be fed to IC3 and this is well below its 3.3V supply, which also acts as the ADC reference voltage.

So basically, the micro can measure the voltage across each cell by controlling the state of its output pins 13/RB4 (to A0), 14/RC2 (to A1), 15/RC1 (to IC2 EN) and 16/RC0 (to IC1 EN). Because it uses the same circuitry in each case, errors should be consistent, making for accurate cell voltage comparisons.

IC4 has a CMRR of at least 90dB with unity gain, so the error due to absolute cell voltage variation is tiny – with 30V between the bottom and top cell voltages, the resulting error will be less than 1mV. Besides noise, the other source of error is variation in the on-resistance between the analogue switches in IC1 and IC2. However, since IC4 has an extremely high input impedance of around 400MΩ, this error will also be negligible; less than 10µV.

Cell balancing

During charging, microcontroller IC3 scans the cells about once per second, to determine if there is a significant difference in their voltages. If there is, it switches on one of Q1a-Q3b, Q4 or Q12 to shunt some current around it, reducing that cell's charge rate.

One of these MOSFETs is connected across each cell, with a 10Ω series resistor at either end (the bottom cell is slightly different). Many of these resistors are shared, to cut down on the component count, meaning normally only one MOSFET will switch on at a time, to keep dissipation within component limits.

The bottom-most cell is discharged by N-channel MOSFET Q12. Its gate is driven directly from output pin 10 (RB7) of micro IC3 and when that line goes high, it sinks current from the positive terminal of this cell through a pair of series-connected 10Ω resistors to ground. Assuming this is a fully-charged Li-Po cell at around 4.2V, the shunt current is 4.2V ÷ 20Ω = 210mA.

If the battery is being charged at, say 5A, this means that 4.2% of the charge current will be shunted around this cell, so it will charge more slowly than the others and eventually the voltages will re-balance. If charging is not occurring then this cell will simply discharge at a rate of 210mA, until its voltage has been reduced to be in line with the other cells.

The other seven cells (or however many are present) are discharged by one of P-channel MOSFETs Q1-Q4. Six of these are part of DMP3085 dual MOSFETs, while the seventh is a single DMP2215 MOSFET. Each is normally held off by a 47kΩ resistor between its gate and source terminal, and switched on when the gate is pulled to ground by one of Q5-Q11, which are small-signal N-channel MOSFETs.

Like Q12, these are driven directly from the outputs of micro IC3, from pins 2-9. These are logic-level MOSFETs and require less than 2V at the gate to sink more than 100mA. Q5-Q11, in combination with the gate pull-up resistors, effectively form level shifters to provide the different voltage levels to drive the gates of Q1-Q4.

The DMP3085 MOSFETs used have a maximum gate-source voltage of 30V, so Q2 and Q3 require no gate voltage limiting. Q4 does not require gate voltage limiting either, as it's connected across the second-from-bottom cell and so its source will never be more than 9V above ground. However, for Q1a and Q1b, two extra 47kΩ resistors are connected between the drains of Q5/Q6 and their gates to reduce the gate drive voltage to a maximum of –20V.

The discharge MOSFETs do not need to be switched quickly, so the relatively high-value 47kΩ resistors do not interfere with their function.

Power supply

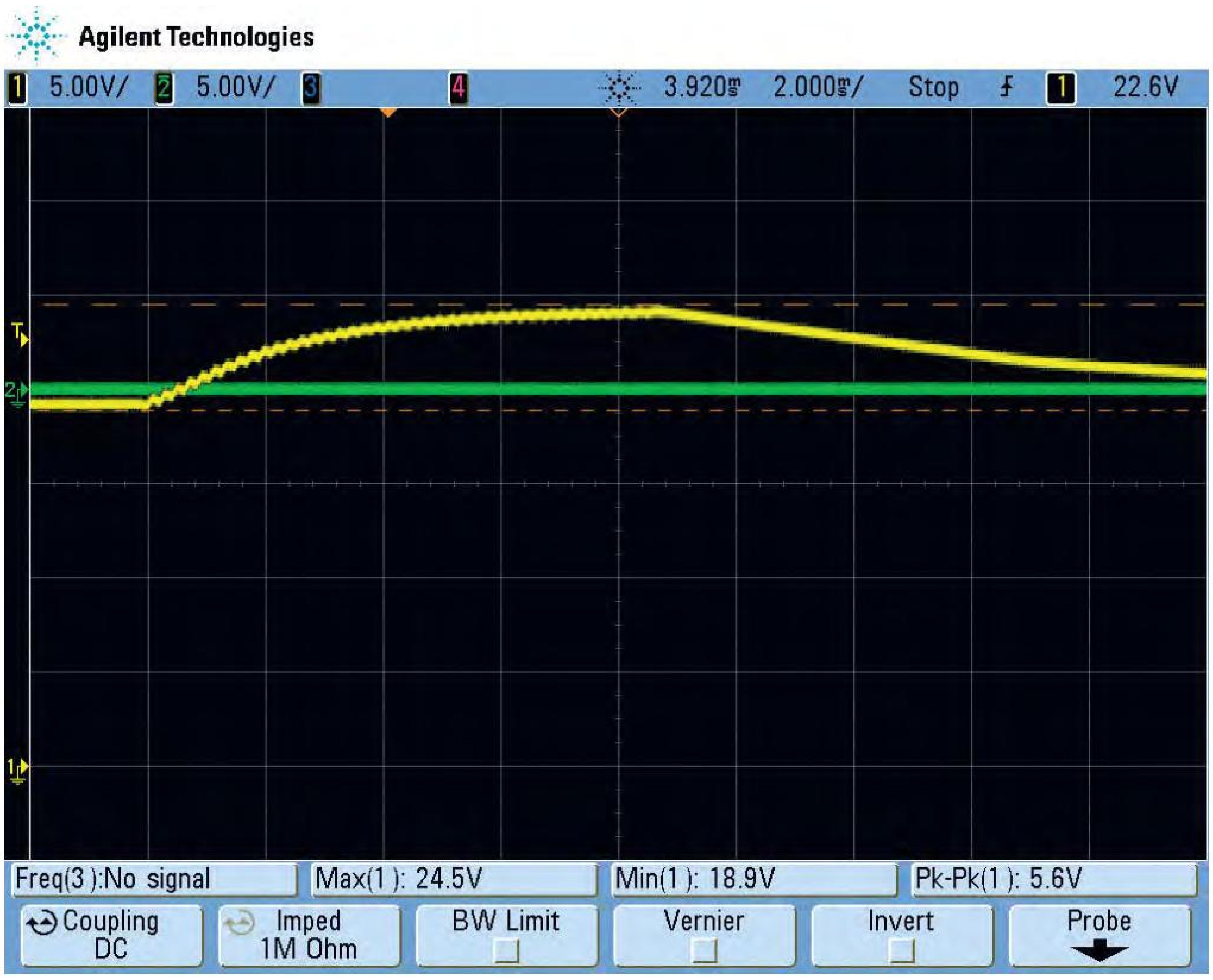
REG1 is fed the full battery voltage via one of dual Schottky diodes D1-D4. A 47Ω filter/dropper resistor reduces dissipation in REG1, an SMD 3.3V low-dropout linear regulator, while also filtering out any hash from the charger or spikes from discharge pulses.

The 3.3V rail supplies microcontroller IC3 and is also used as a reference voltage for its ADC, as stated earlier.

The V_{BAT} rail from the cathodes of D1-D4 also powers multiplexers IC1 and IC2 via series Schottky diodes D5 and D6. These diodes provide protection for IC1 and IC2 against over-voltage at their inputs, since their internal clamp diodes will automatically boost the supply if this happens (and D5/D6 would become reverse-biased). Normally this is not an issue, but when a battery is initially plugged in, not all of its pins may make contact at the same time, so we're protecting these ICs as per the suggested arrangement in the data sheet.

The power supply for IC4 is somewhat more complex. To avoid draining the battery when it isn't being charged or balanced, micro IC3 switches off IC4 using PNP transistor Q14. To switch Q14 on, IC3 drives its RB6 output high (pin 11), which charges N-channel MOSFET Q13's gate via an RC filter. Q13 then sinks current from Q14's base via a 10kΩ current-limiting resistor, turning it on and allowing current to flow to IC4's supply pin via D7.

But that isn't the end of the story because while IC4 can handle input voltages down to its negative rail (ie, GND), the inputs must remain below its positive rail for correct operation. The voltage between the positive-most input and the positive supply rail must be at least 1V plus half the output voltage to remain in the common-mode operating range, which in our case means we need a 'headroom' of around 3.1V (1V + 4.2V ÷ 2).



Freq(3):No signal | Max(1): 24.5V | Min(1): 18.9V | Pk-Pk(1): 5.6V

Coupling DC | Imped 1M Ohm | BW Limit ☐ | Vernier ☐ | Invert ☐ | Probe

Fig.3: operation of the charge pump which supplies IC4. Initially, IC4's supply (yellow) is below the battery voltage (green) due to the two Schottky diodes and one PNP transistor its supply current must pass through. Once the charge pump begins operation, it quickly climbs above the battery voltage, eventually settling about 4V higher after 8ms or so. The micro then quickly takes the measurement using its ADC before the supply voltage drops.

The forward voltage of D1-D4 and D7 means that normally IC4's supply will be around 0.6V below the positive-most battery terminal, so we need to boost its supply by 3.1V + 0.6V = at least 3.7V to correctly sense the top cell voltage.

So, before measuring the voltage of the top-most cell, after RB6 is brought high and the 1µF capacitor at Q13's gate is fully charged, IC3 pulses its RB6 output around 50 times before taking the first measurement, with a frequency of around 5kHz. This drives a charge pump which increases IC4's supply voltage to about 4V above the battery voltage, allowing it to properly measure the voltage of the top cell(s).

Fig.3 shows how the supply voltage to IC4 rises during this period, from a little below the 20V battery voltage in this example to around 24V.

It works as follows: when RB6 goes low, 1µF capacitor C1 charges from the battery supply via Q14 and D8, to around 0.75V less than the battery (point 'a', Fig.2). When RB6 goes high again, point 'a' increases by about 3.3V, to around 2.5V above the battery voltage. C2 is then charged to slightly less than this (at point 'b'), via one half of dual series Schottky diode D9.

When RB6 next goes low, C3 charges to around 2V above the battery voltage via the second half of D9 (point 'c'). When RB6 goes high again, point 'c' is boosted to around 4V above the battery voltage and current flows through the lower half of dual Schottky diode D7, forming IC4's supply. This drops a little during RB6's off-time, but remains sufficiently high to complete several ADC conversions.

By starting with Q13's gate at 3.3V and keeping the duty cycle relatively high, Q13 is prevented from switching off before the charge pump has done its work, despite the fact that RB6 is being modulated.

Balance current

The 10Ω resistors have been chosen to limit current to a safe level with lithium-based rechargeable cells. For

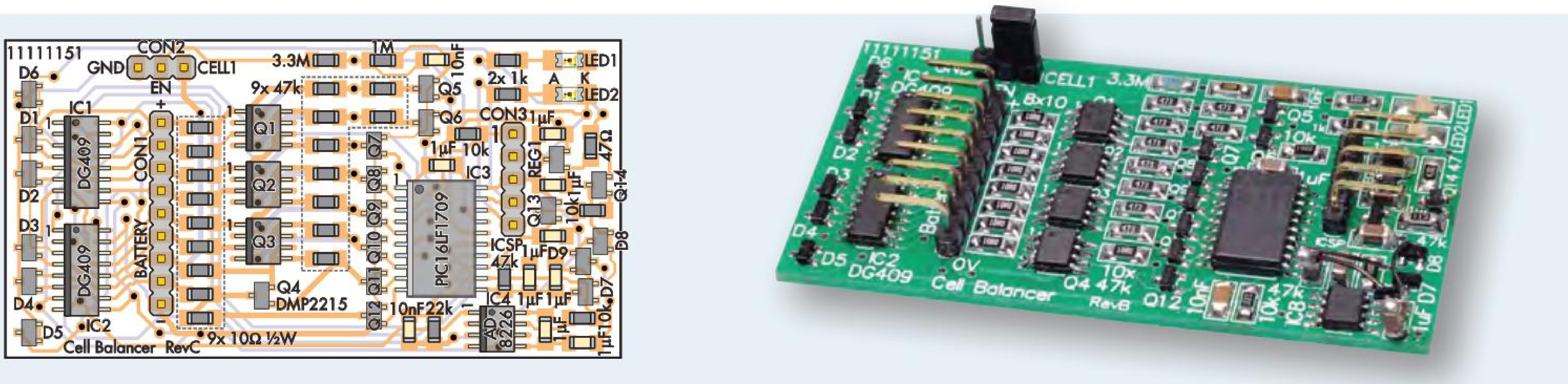


Fig.4: all SMD components are mounted on the top of the double-sided PCB. The pin headers can be straight or right-angle types and can be fitted on either side. Take care with the orientation of IC1-IC4, Q1-Q3, LED1 and LED2. The other components are either non-polarised or their orientation is fairly obvious. Note: photo shows prototype PCB assembly.

NiMH/Nicad, since the cell voltage is substantially lower (less than half), ideally 4.7Ω 0.5W resistors should be substituted. The unit will still operate with 10Ω resistors, but the shunt current will be below 100mA and this may be insufficient to keep the cells balanced, depending on the charge current.

Note though that 4.7Ω is too low for use with Li-ion, LiPo and $LiFePO_4$ batteries as they would dissipate nearly 1W each $((4.3V \div 2)^2 \div 4.7\Omega)$.

Software operation

The first thing that the software does, after setting up the input and output pins, is to determine the number of cells in the battery by measuring the voltage of each one and checking that it is above a minimum threshold. It expects to find a contiguous set of at least two cells starting from the bottom; otherwise, it flashes red LED1, waits a short time, then checks again. Once a valid battery has been detected, normal operation begins.

When checking for the presence of a cell, the corresponding shunt/discharge MOSFET is switched on briefly to remove any stray charge that may be present, which could give a false reading.

The main loop checks the voltage on pin 17 and goes into a sleep mode if it is below the 0.95V threshold (corresponding to a 4.085V trigger threshold with the values shown in Figs.1 and 3). After spending some time in low-power sleep mode, the watchdog timer wakes the chip up and the pin 17 voltage is checked again.

Assuming pin 17 is at least 0.95V, the software switches on power to IC4, waits for its bypass capacitor to charge, then initiates the charge pump to bring its supply voltage up. Once that's complete it quickly scans the cells, from the highest to the lowest, measuring the voltages and storing them. It then makes a decision about whether to shunt/discharge any cells. If they're all basically equal, it ceases balancing and goes back to the main loop.

If balancing starts, the cell with the highest voltage is shunted/discharged. If there is a tie then they are handled in a round-robin fashion to balance the shunt current evenly. Each time, after a few seconds of shunting/discharging, the cell voltages are re-checked and a new decision is made.

Balance initiation

You can connect an external signal to pin 2 of CON2 to initiate balancing; for example, you could connect an output from your battery charger that goes high (to at least 4.5V) during charging. For a lower threshold, reduce the value of the 3.3MΩ resistor. For example, to suit a 3.3V signal, use a 1MΩ resistor, setting the threshold to 1.9V.

Alternatively, you can short out pins 1 and 2 of CON2, eg, with a jumper shunt. Balancing then starts whenever the bottom-most cell of the pack exceeds 4.1V. This voltage was chosen so that when a Li-ion or Li-Po battery is approaching full charge, balancing will begin but will cease once the battery has been discharged below approximately 90% of full charge. This prevents unnecessary battery drain if the cells become imbalanced during discharge.

There's no inherent reason why cells cannot be balanced during discharge; in fact, arguably this is a good idea. However, it will increase battery current drain slightly and may reduce shelf-life after charging. It may also trigger low-battery cut-out on the powered device earlier. However, this could be a good thing, as it will prevent any single cell from being over-discharged.

The balance initiation threshold can also be changed by selecting a different value for the 3.3MΩ resistor. Simply take the desired cut-off voltage, divide by 0.95, subtract one and pick the nearest resistor value in megohms. This will be necessary for different battery chemistries (eg, NiMH).

Construction

All components are fitted to one side of the PCB, with the possible exception of the headers, depending on your requirements. Use the PCB overlay diagram (Fig.4) as a guide for assembly.

Start by fitting the ICs. The simplest method is to apply a little solder to one of the pads, then heat that solder while sliding the IC into place. Once you've done that, check carefully that pin 1 is oriented correctly, which is usually indicated by a divot or dot in the corner.

Failing that, look for a bevelled edge on the IC package. Then check that all the pins are correctly centred over their pads. If not, reheat the initial solder joint and nudge the IC into place. You can then solder the remaining pins and, finally, refresh the initial solder joint.

Follow with MOSFETs Q1-Q3 which are in similar packages to IC4. Next, install all the components in SOT-23 packages, which includes all the diodes, the remaining MOSFETs and bipolar transistor Q14, as well as REG1. A similar method can be used, where one pin is tacked down before the other two are soldered and the initial joint refreshed. Be careful not to get any of these parts mixed up as they all look very similar.

Follow with the resistors and capacitors using a similar technique. The resistors will have an abbreviated code printed on the top showing the value, eg, 223 for 22kΩ (22 × 10^3). The capacitors will be unmarked although you will probably be able to pick them apart as the 1µF types should be physically larger. If you're planning on using 4.7Ω resistors rather than 10Ω, keep that in mind.

That just leaves two SMDs, both LEDs. You will need to determine which end is the cathode. This is often marked on the package with a green dot; however, we've seen LEDs which mark the anode with a green dot too, so it's safest to check. Generally, this can be done with a DMM set on diode test mode. Probe each end of the LED with the leads. If it lights up, the red lead is connected to the anode and the black to the cathode. If not, try flipping the LED around.

Once you've worked out which end is the cathode (and also revealed the colour), solder it in place. Note that LED1 is red and LED2 is green and that the cathode (indicated with a K) goes towards the righthand edge of the PCB.

Battery connector CON1 can be soldered to either side of the PCB and you can use a straight or right-angle header. We used a right-angle header on the top of the board to minimise the overall thickness of the unit. You may wish to use a header with fewer than nine pins, to suit your battery connector, as this will make it easier to plug in. However, you could just solder in a 9-pin header to suit any battery pack with 2-8 cells.

CON3 can be omitted if your microcontroller is already programmed. We used a right-angle programming header, again to minimise thickness.

For CON2, we used a straight header as we simply fitted a jumper shunt so that balancing would begin automatically once the battery reached a sufficient cell voltage. However, you could simply fit a wire link between 'EN' and 'CELL1' if desired. Alternatively, connect a pair of wires between GND and EN, with or without the pin header.

Note that, while it would be possible to leave out some components if you do not need to handle batteries with more than six cells, we'll leave it to individual constructors to figure out which ones can be omitted.

Usage

If IC3 has not already been programmed, you need to download the hex file from the *EPE* website. Program the chip using a PICkit 3 or a similar PIC programmer. You can use the PICkit 3 to power IC3, but be careful not to exceed its 3.6V maximum supply rating.

Ideally, it's a good idea to do some basic checks before connecting a battery. If you have a current-limited bench supply, set it to 12-24V at 10mA and connect it between pins 1 and 9 of CON1, with the negative terminal to pin 9. Once the on-board capacitors charge, the current drain should drop to just a few milliamps and the red LED should flash, indicating a battery is not detected.

If you don't have a bench supply, you can use any DC source with a series resistor of say 470Ω 0.5W for ~12V or 1kΩ 0.5W for ~24V.

Assuming all is OK, connect the battery, taking care to orient the plug correctly as the header is not polarised. In theory, the unit should survive a reversed supply connection, at least in the short term, but the 10Ω resistors could potentially overheat as the parasitic diodes in MOSFETs Q1-Q4 will conduct.

After a couple of seconds you should see the green LED flash once for each cell in the battery. If you have joined EN and CELL1 on CON2, depending on the battery voltage, the unit may then begin the balancing operation. Otherwise, it will go into sleep mode and both LEDs will remain off.

If driving the EN pin externally, wire this up to your charger so that it will be driven high during charging. You can then switch on the charger and check that the red and green LEDs illuminate together briefly, to indicate that the unit has 'woken up'. If the battery needs balancing, you will see further flashes.

When balancing occurs, green LED2 will flash rapidly and then switch off. The number of flashes indicates which cell is being shunted/discharged. Once the cells have been balanced, green LED2 will be switched on for around one second, then switch off.

Error indication

If an error condition is detected (eg, an unexpected low cell voltage), red LED1 will flash rapidly. If the EN pin drops below 0.95V while balancing is still active, red LED1 will switch on for around one second and then the unit will go back into sleep mode until the EN pin voltage rises again.

PoLabs
For more information or software download please visit
www.poscope.com/epe
PoKeys
Connect, Control
- USB
- Ethernet
- Web server
- Modbus
- CNC (Mach3/4)
- IO
- PWM
- Encoders
- LCD
- Analog inputs
- Compact PLC
Stepper motor drivers
Drive
- up to 256 microsteps
- 50 V / 6 A
- USB configuration
- Isolated
- up to 32 microsteps
- 30 V / 2.5 A
PoScope Mega1+
PoScope Mega50
Measure
- up to 50MS/s
- resolution up to 12bit
- Lowest power consumption
- Smallest and lightest
- 7 in 1: Oscilloscope, FFT, X/Y, Recorder, Logic Analyzer, Protocol decoder, Signal generator

EPE EVERYDAY PRACTICAL ELECTRONICS

BACK ISSUES

We can supply back issues of *EPE* by post, most issues from the past five years are available. An *EPE* index for the last five years is also available at **www.epemag.com**. Where we are unable to provide a back issue a photocopy of any one article (or one part of a series) can be purchased for the same price. Issues from Jan. 99 are available on CD-ROM or DVD-ROM – and back issues from recent years are also available to download from **www.epemag.com**. Please make sure all components are still available before commencing any project from a back-dated issue.

DID YOU MISS THESE?

BACK ISSUES ONLY £5.00 (each inc. UK p&p.)

Overseas prices £5.80 each surface mail, £6.80 each airmail.

We can also supply issues from years: 2006 (**except** Jan., Feb., Mar., Apr., May, July). 2007 (**except** June, July, Aug), 2008 (**except** Aug, Nov, Dec) 2009 (**except** Jan, Mar, Apr.). 2010 (**except** May, June, July, August, Oct, Nov, Dec) 2011 (**except** Jan) Jan 2014.

MAR '16

PROJECTS • Spark Energy Meter – Part 2 • 6-Digit Retro Nixie Clock – Part 2 • Modifying The Currawong Valve Amplifier •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 2 • Audio Out • Practically Speaking • Audio Out Special – Product Review • Net Work • PIC n' Mix • Circuit Surgery • Electronic Building Blocks • Max's Cool Beans •

APR '16

PROJECTS • Appliance Insulation Tester • Low Frequency Distortion Analyser • Really Bright 12/24V LED Oyster Light •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 3 • Audio Out • Interface • Net Work • PIC n' Mix • Circuit Surgery • Electronic Building Blocks • Max's Cool Beans •

MAY '16

PROJECTS • 2-Channel Balanced Input Attenuator For Audio And Digital Scopes • Appliance Leakage Tester • 4-Output Universal Voltage Regulator •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 4 • Practically Speaking • Net Work • PIC n' Mix • Circuit Surgery • Electronic Building Blocks • Max's Cool Beans •

JUN '16

PROJECTS • The Bad Vibes Infrasound Snooper • Audio Signal Injector And Tracer • Champion Preamp •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 5 • Interface • Net Work • PIC n' Mix • Circuit Surgery • Electronic Building Blocks • Max's Cool Beans • Audio Out • Alan Sugar Autobiography Review

JULY '16

PROJECTS • Driveway Monitor – Part 1 • Intelligent Charger For Nicad And NiMH Batteries • Install USB Charging Points In Your Car •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 6 • Practically Speaking • Net Work • PIC n' Mix • Circuit Surgery • Electronic Building Blocks • Max's Hot Beans •

AUG '16

PROJECTS • Low-Cost, Accurate Voltage/Current/Resistance Reference • Checking And Calibrating Multimeters • Driveway Monitor – Part 2 • USB Power Monitor •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 7 • Interface • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Max's Cool Beans •

SEPT '16

PROJECTS • Compact Hybrid Switchmode 100W Bench Supply – Part 1 • Speedo Corrector – Mk.3 • LED Party Strobe •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 8 • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Max's Hot Beans • Electronic Building Blocks •

OCT '16

PROJECTS • Arduino-Based USB Electrocardiogram • 5-Element Yagi Antenna • Compact Hybrid Switchmode 100W Bench Supply – Part 2 •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 9 • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Electronic Building Blocks • Practically Speaking •

NOV '16

PROJECTS • Fingerprint Access Controller • Cheap Programmer For The PIC32 Microcontroller • Compact Hybrid Switchmode 100W Bench Supply – Part 3 • Ingenuity Unlimited •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 10 • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Electronic Building Blocks • Interface • Max's Hot Beans •

DEC '16

PROJECTS • Universal Loudspeaker Protector • 9-Channel Infrared Remote Control • Revised USB Charger Regulator With Low Battery Cut-Out •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 11 • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Electronic Building Blocks • Max's Hot Beans •

JAN '17

PROJECTS • High-Performance Stereo Valve Preamplifier – Part 1 • High Visibility 6-Digit LED GPS Clock – Part 1 • 5-Element Yagi Specifically For DAB Radio •
FEATURES • Techno Talk • Teach-In 2016 – Exploring The Arduino – Part 12 • Interface • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Electronic Building Blocks • Max's Hot Beans •

FEB '17

PROJECTS • Solar MPPT Charger And Lighting Controller – Part 1 • Check Your Turntable's Speed With This White LED Strobe • High-Performance Stereo Valve Preamplifier – Part 2 • High Visibility 6-Digit LED GPS Clock – Part 2 •
FEATURES • Techno Talk • Meet The Mighty Micromite – Part 1 • Net Work • PIC n' Mix • Circuit Surgery • Audio Out • Electronic Building Blocks • Max's Cool Beans •

MAR '17

PROJECTS • Speech Timer For Contests & Debates • Solar MPPT Charger And Lighting Controller – Part 2 • Arduino-Based Fridge Monitor And Data Logger • High Visibility 6-Digit LED GPS Clock – Part 2 • Ingenuity Unlimited •
FEATURES • Techno Talk • Meet The Mighty Micromite – Part 2 • Net Work • PIC n' Mix • Circuit Surgery • *EPE* Product Review – LabNation SmartScope • Interface • Electronic Building Blocks • Max's Cool Beans •

ORDER FORM – BACK ISSUES – PHOTOCOPIES– INDEXES

☐ Send back issues dated. . . . .

☐ Send photocopies of (article title and issue date) . . . .

Name . . . .

Address. . . . .

. . . . .Tel: . . . .

☐ I enclose cheque/P.O./bank draft to the value of £ . . . .

☐ Please charge my Visa/Mastercard/Maestro £ . . . .

Card No . . . .

Valid From . . . . Card Expiry Date . . . . Card Security Code . . . .
(The last 3 digits on or just under the signature strip)

SEND TO: **Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU.**
Tel: 01202 880299. Fax: 01202 843233.
E-mail: orders@epemag.wimborne.co.uk **On-line Shop**: www.epemag.com

Payments must be in £ sterling – cheque or bank draft drawn on a UK bank. Normally posted within seven days of receipt of order. Send a copy of this form, or order by letter if you do not wish to cut your issue.

M04/17

High Impact Embedded Graphics GUI Design Has Never Been This Simple

Free Visual Design Tools & Graphics Libraries for Your GUI Applications

Coffee & Tea
Café
Brew Over Ice
Coffee
Strong
Tea/Other
Hot Cocoa
8 oz
Current Outside
78°
Cloudy
72°
80°
74°
23% Humidity
ALARM SYSTEM
1 2 3
4 5 6
7 8 9
* 0 #

Microchip offers an industry leading complement of comprehensive visual Graphical User Interface (GUI) development tools, software graphics libraries and hardware tools for all your 32-bit graphics needs.

Our graphics solutions are supported with the free MPLAB® Harmony software framework and offers developers the choice of two best-in-class tools:

① Our MPLAB® Harmony Graphics Composer works in conjunction with our MPLAB Harmony Graphics Library to help you generate professional looking GUIs without writing a single piece of code!

OR

② You may choose SEGGER emWin Pro as your graphics library and take advantage of its expansive list of widgets and the SEGGER toolchain.

Multimedia Expansion Board II (DM320005-2)

Get started today by downloading training material, documentation and tools!

microchip DIRECT
www.microchipdirect.com

MPLAB® HARMONY

MICROCHIP

www.microchip.com/MCU32GFX

The Microchip name and logo, the Microchip logo and MPLAB are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries. All other trademarks are the property of their registered owners.
© 2017 Microchip Technology Inc. All rights reserved. DS60001462A. MEC2138Eng01/17

Meet the mighty Micromite

MicroMite v2.2
MPU
1
20
21
22
19
18
17
16
15
14
42
43
44
36
31
30

Part 3: Programming the Micromite in MMBasic

by Geoff Graham

The Micromite is an amazing device. A low-cost microcontroller programmed in a Microsoft-compatible version of BASIC with floating point, arrays and extensive string handling. The Micromite can interface to a variety of devices including touch-sensitive LCD panels and a host of sensors for temperature, humidity, GPS and more. Even better, the microcontroller only costs a couple of pounds and the BASIC interpreter is free. Available in a user-friendly 28-pin package, the Micromite makes a great controller for your heating system, lighting manager or whatever else your imagination can dream up.

Do you like the idea of the Micromite but don't know how to program in BASIC? This tutorial is the answer. It will guide you through the basics of programming in the BASIC language – leaving you ready to write your first program and make your special project a reality.

The Micromite is programmed using the BASIC programming language. The Micromite version of BASIC is called MMBasic (short for **M**icro**M**ite **BASIC**) which is similar to the Microsoft BASIC interpreter that was popular years ago.

The BASIC language was originally developed in 1964 by Dartmouth College in the US as a computer language for teaching programming to beginners. For that reason, it is easy to use and learn. At the same time, it has proved to be a competent and powerful programming language and became very popular in the 70s and 80s. Even today, quite a few large commercial data systems are still written in the BASIC language.

For the Micromite, the greatest advantage of BASIC is its ease of use. Some more modern languages, such as C and C++ can be truly mind bending, but with BASIC you can start with a one-line program and get something sensible out of it. MMBasic is also powerful in that you can control the I/O pins on the Micromite, interface to things like an LCD display or IR remote control, and communicate with other chips using a range of built-in communications protocols.

About the only downside to using a BASIC interpreter is that it is not as fast as a fully compiled language like C or C++. However, on a fast microcontroller such as the PIC32, MMBasic will execute each command in an average of 50µs or faster. This speed is suitable for most applications – for example, fast enough to respond to a high-revving engine and generate signals such as ignition triggers. And if that is not fast enough you can always embed compiled C functions in your BASIC program.

This tutorial will go through many aspects of the BASIC language, but it cannot cover everything. For example, many commands have additional features that are only used in special circumstances. So it would be worthwhile downloading the manual and having it handy as you read through the following pages. That way you can explore the full detail of a command that might interest you. The *Micromite User Manual* can be downloaded for free, along with the firmware from *EPE* or the author's website: **http://geoffg.net/micromite.html**

Getting started

On start up, the Micromite issues the command prompt (>) on the console and waits for some input. At this time you have a wide range of commands that you can execute. These include setting some options (the `OPTION` command) or perhaps listing the program held in Flash memory (`LIST`) or even editing it (`EDIT`). Most times, the command is just `RUN`, which instructs MMBasic to run the program already held in Flash memory.

However, almost any command can be run at the command prompt, and this is often used to test a command and see how it works. A simple example is the `PRINT` command (more on this command later) – you can test it by entering the following at the command prompt:

```
PRINT 2 + 2
```

Not surprisingly, MMBasic will print out the number '4' before returning to the command prompt.

A BASIC program consists of a number of statements or commands, each of which causes the BASIC interpreter to do something. Normally, each statement is on its own line, but you can have multiple statements in the one line separated by the colon character (`:`).

The program starts running at the first line and continues until it runs off the end of the program or hits an END command – at which point MMBasic will display the command prompt (>) on the console and wait for something to be entered.

One very useful feature of MMBasic is the `CTRL-C` sequence (hold down the 'CTRL' key when pressing the 'C' key). This is called the break key or character. When you type this on the console's input it will interrupt whatever program is running and immediately return control to the command prompt. This can get you out of all sorts of difficult situations. For example, if you entered the following at the command prompt:

```
DO : LOOP
```

You would cause MMBasic to enter a continuous loop. If you try entering, CTRL–C you will see how this will immediately break out of the loop and return MMBasic to the prompt. Remember CTRL–C – it will prove useful at some time in the future.

Last month, I described a number of ways that you can get your program into the Micromite. You could write it on a desktop computer using a text editor like Notepad and then transfer it via the console connection using the MMBasic commands AUTOTEXT or XMODEM. However, the easiest way of getting started is to use the editor built into MMBasic. This enables you to enter programs, save them to the Micromite's memory and then change them later if needed.

All programs are saved into the Flash memory of the PIC32 chip. The command MEMORY reports how much memory was used by the program; for example:

```
Flash:
  21K (35%) Program (805 lines)
  39K (65%) Free
RAM:
   9K (16%) 5 Variables
  18K (32%) General
  26K (52%) Free
```

Flash memory is non-volatile, which means that it will retain its contents when the power is removed. This is important for an embedded controller where the power can be lost at any time.

PRINT command

Arguably the most useful command in MMBasic is the PRINT command. Its job is simple; to print something on the console. This is mostly used to tell you how your program is running and can consist of something simple such as 'Pump running' or 'Total Flow: 23 litres'.

In its simplest form the PRINT command will just print whatever is on its command line. So, for example PRINT 54 will display on the console the number 54 followed by a new line. The PRINT command can have multiple items to print, for example:

```
PRINT 12 55 99
```

This will print the numbers specified, each with a single space between each number. The data to be printed can be 'expressions', which mean something to be calculated. We will cover expressions in more detail later, but as an example, consider PRINT 5*(9+2), which prints the number '55'.

There is one extra point to note about the PRINT command; it automatically adds a new line (the ASCII characters 'CR' and 'LF') after printing the result. This is handy for normal use, but sometimes you do not want this, so you can suppress it by adding a semicolon (;) to the end of the command line, for example: PRINT 55;

Variables

Before we go much further we need to define what a 'variable' is because they are fundamental to the operation of the BASIC language. A variable is simply a place to store an item of data (ie, its 'value').

Variables can be any one of three types. The most common is floating point and this is automatically assumed if the type of the variable is not specified. A 'floating-point' number is an ordinary number, which can contain a decimal point. For example 3.45, 99 or 100.01 are all floating-point numbers.

The other two types are integer and string, and we will cover them later.

A variable can be used to store a number and it can then be used in the same manner as the number itself, in which case it will represent the value of the last number assigned to it. As a simple example:

```
A = 3
B = 4
PRINT A + B
```

This displays the number '7'. In this case both A and B are variables and MMBasic used their current values in the PRINT statement.

BASIC will automatically create a variable when it first encounters it, so the statement A = 3 both created a floating point variable (the default type) with the name A and then assigned it the value of 3.

The name of a variable must start with a letter, but the remainder of the name can use letters, numbers, the underscore or the full stop. The name can be up to 32 characters long and the case of the letters used is not important. Here are some examples:

```
Total_Count
ForeColour
temp3
count
```

You can change the value of a variable anywhere in your program by using the assignment command, for example:

```
variable = expression
```

```
CTemp = (FTemp – 32) * 0.5556
```

In this example both CTemp and FTemp are variables and this line converts the value of FTemp (in degrees Fahrenheit) to degrees Celsius and stores the result in the variable CTemp.

IF statement

Making decisions is at the core of most computer programs, and in BASIC that is usually done with the IF statement. This is written almost like an English sentence:

```
IF condition THEN action
```

The condition is usually a comparison such as equals, less than or more than; for example:

```
IF Temp < 20 THEN HeaterOn
```

Temp would be a variable holding the current temperature and HeaterOn the action to be done. There is a wide range of conditions that you can use:

=	equals
<	less than
>	greater than
<=	less than or equals
>=	greater than or equals

You can also add an ELSE clause, which will be true if the initial condition tested false. For example, this will execute different actions when the temperature is under or over 20:

```
IF Temp < 20 THEN HeaterOn ELSE
CoolingOn
```

The previous examples all used single-line IF statements, but you can also have multi-line IF statements, which look like this:

```
IF condition THEN
    TrueActions
ELSE
    FalseActions
ENDIF
```

Unlike the single-line IF statement, you can have many true actions with each on their own line and similarly many false actions. Generally, the single-line IF statement is handy if you have a simple action that needs to be taken, while the multi-line version is much easier to understand if the actions are numerous and more complicated.

An example of a multiline IF statement with more than one action is:

```
IF Temp < 20 THEN
    HeaterOn
    RedLightOn
ELSE
    CoolingOn
    BlueLightOn
ENDIF
```

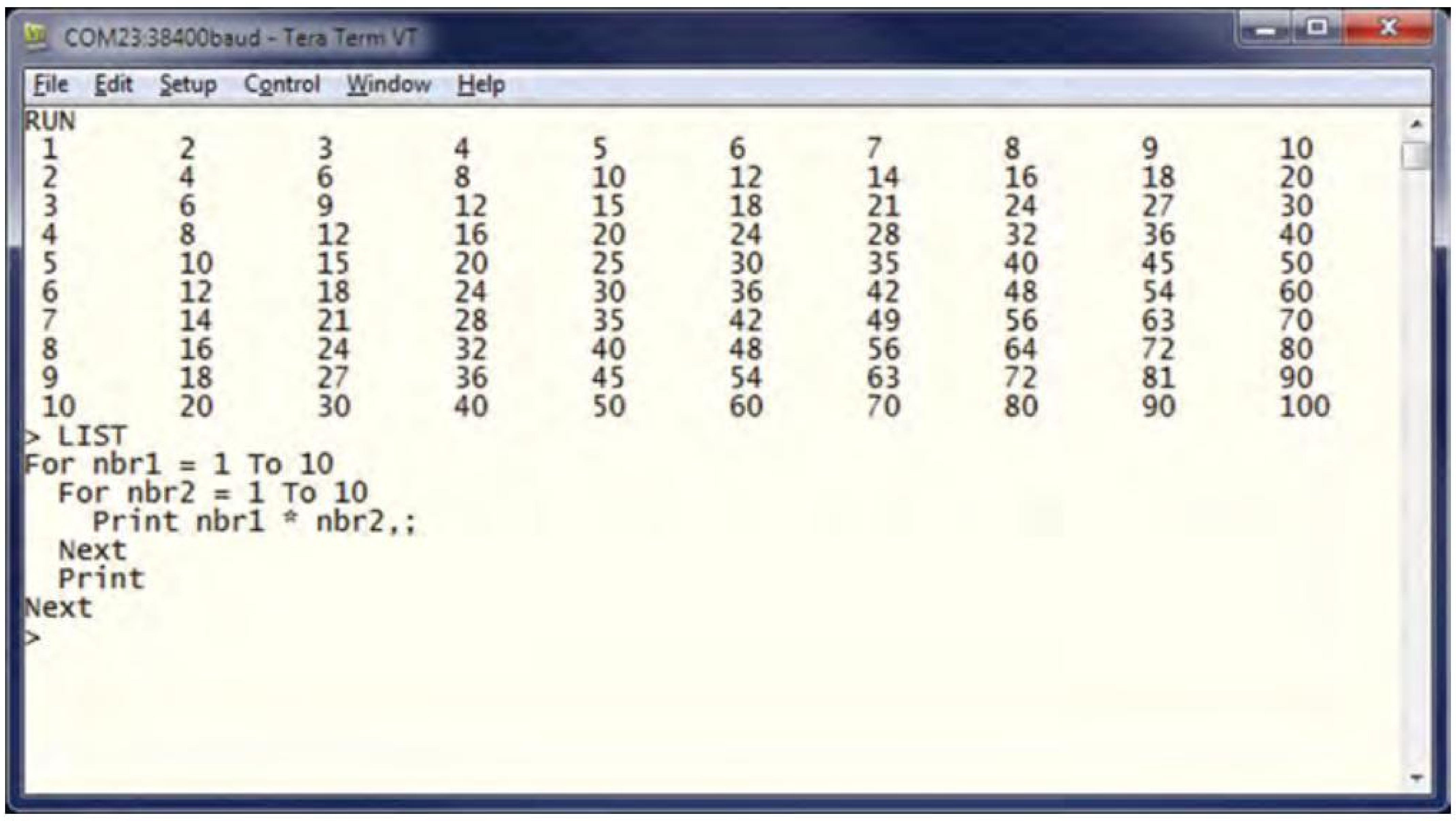
Note that in the above example we indented each action to show what part of the IF structure it belongs to. This is not mandatory, but it makes a program much easier to understand for someone who is not familiar with it and is highly recommended. You will find that we use indentations in all our examples for this reason.

FOR loop

Another common function in programming is looping around through a set of actions. For example, you might want to step through all seven days in the week and perform some function. BASIC provides the FOR loop for this type of job, and it works like this:

```
FOR day = 1 to 7
  Do something based on 'day'
NEXT
```

This starts by creating the variable day and assigning the value of 1 to it. The program then executes the following statements until it comes to


COM23:38400baud - Tera Term VT
File Edit Setup Control Window Help

```
RUN
 1       2       3       4       5       6       7       8       9       10
 2       4       6       8       10      12      14      16      18      20
 3       6       9       12      15      18      21      24      27      30
 4       8       12      16      20      24      28      32      36      40
 5       10      15      20      25      30      35      40      45      50
 6       12      18      24      30      36      42      48      54      60
 7       14      21      28      35      42      49      56      63      70
 8       16      24      32      40      48      56      64      72      80
 9       18      27      36      45      54      63      72      81      90
 10      20      30      40      50      60      70      80      90      100
> LIST
For nbr1 = 1 To 10
  For nbr2 = 1 To 10
    Print nbr1 * nbr2,;
  Next
  Print
Next
>
```

Fig.1. Program and gnerated output for a multiplication table

the NEXT statement. This tells the BASIC interpreter to increment the value of day, go back to the previous FOR statement and re-execute the following statements a second time. This will continue looping around until the value of day exceeds 7 and the program will then continue with the statements following the NEXT.

As a simple example, you can use the FOR loop to print out the multiplication table that we all learnt at school. The program for this is not complicated:

```
FOR nbr1 = 1 to 10
  FOR nbr2 = 1 to 10
    PRINT nbr1 * nbr2,;
  NEXT
  PRINT
NEXT
```

The output will look like that shown in Fig.1, which also shows the listing of the program. You need to work through the logic of this example line by line to understand what it is doing. Essentially, it consists of one loop inside another. The inner loop, which increments the variable nbr2, prints one horizontal line of the table. Note that the PRINT statement is terminated with a comma and a semicolon. The comma instructs MMBasic to tab to the next column and the semicolon will suppress the automatic carriage return/line feed characters that are normally added to the end of the output.

When the inner loop has finished it will execute the following PRINT command, which has nothing to print – so it will simply output a new line (ie, terminate the line printed by the inner loop). The program then executes another iteration of the outer loop by incrementing nbr1 and re-executes the inner loop again. Finally, when the outer loop is exhausted (when nbr1 exceeds 10) the program will reach the end and terminate.

DO loop

Another method of looping is the DO LOOP structure, which looks like this:

```
DO WHILE condition
   statement
   statement
LOOP
```

This will start by testing the condition, and if it is true the statements will be executed until the LOOP command is reached, at which point the condition will be tested again and if it is still true the loop will execute again. The 'condition' is the same as in the IF command (ie, X < Y). For example, the following will keep printing the word 'Hello' on the console for the first four seconds after being run:

```
DO WHILE Timer < 4000
  PRINT "Hello"
LOOP
```

Note that Timer is a function within MMBasic that returns the total time that the program has been running in milliseconds.

A variation on the DO LOOP structure is the following:

```
DO
   statement
   statement
LOOP UNTIL condition
```

In this arrangement the loop is first executed once, the condition is then tested and if the condition is false, the loop will be repeatedly executed until the condition becomes true. For example, similar to the previous example, the following will also print 'Hello' for the first four seconds:

```
DO
  PRINT "Hello"
LOOP UNTIL Timer >= 4000
```

Both forms of the DO LOOP do the same thing – use whatever structure fits with the logic that you want to implement.

Expressions

We used the term 'expression' before and in BASIC it has a specific meaning. It is a mathematical formula that can be resolved by the BASIC interpreter to a single number or value. MMBasic will evaluate an expression using the same rules that we all learnt at school. For example, multiplication and division are performed first, followed by addition and subtraction.

This means that `2 + 3 * 6` will resolve to 20, so will `5 * 4` and also `10 + 4 * 3 – 2`. If you want to force the interpreter to evaluate parts of the expression first you can surround that part of the expression with brackets. For example, `(10 + 4) * (3 – 2)` will resolve to 14 *not* 20, as would have been the case if the brackets were not used. Using brackets does not appreciably slow down the program, so you should use them liberally if there is a chance that MMBasic will misinterpret your expression.

As you would expect, you can use variables in an expression exactly the same as straight numbers. You can also use functions in expressions. These are special operations provided by MMBasic, for example to calculate trigonometric values. As an example, the following will print the length of the hypotenuse of a right-angled triangle using the SQR() function, which returns the square root of a number (a and b are variables holding the lengths of the other sides):

```
PRINT SQR(a * a + b * b)
```

Some other mathematical functions provided by MMBasic include:

SIN(r) sine of r
COS(r) cosine of r
TAN(r) tangent of r
ATAN(r) arctangent of r

Note that in the above functions the value passed to the functions (ie, r) is the angle in radians. In MMBasic you can use the function RAD(d) to convert an angle from degrees to radians (d is the angle in degrees).

Another feature of BASIC is that you can nest function calls within each other. For example, given the angle in degrees (ie, d) the sine of that angle can be found with this expression: SIN(RAD(d)). In this case, MMBasic will first take the value of d and convert it to radians using the RAD() function. The output of this function then becomes the input to the SIN() function.

Console input

There are times when you would like to use the Micromite as a straight computer with all of its input coming from the console and its output going to the same place. For this you need to capture keystrokes from the console. This is done with the INPUT command. In its simplest form the command is:

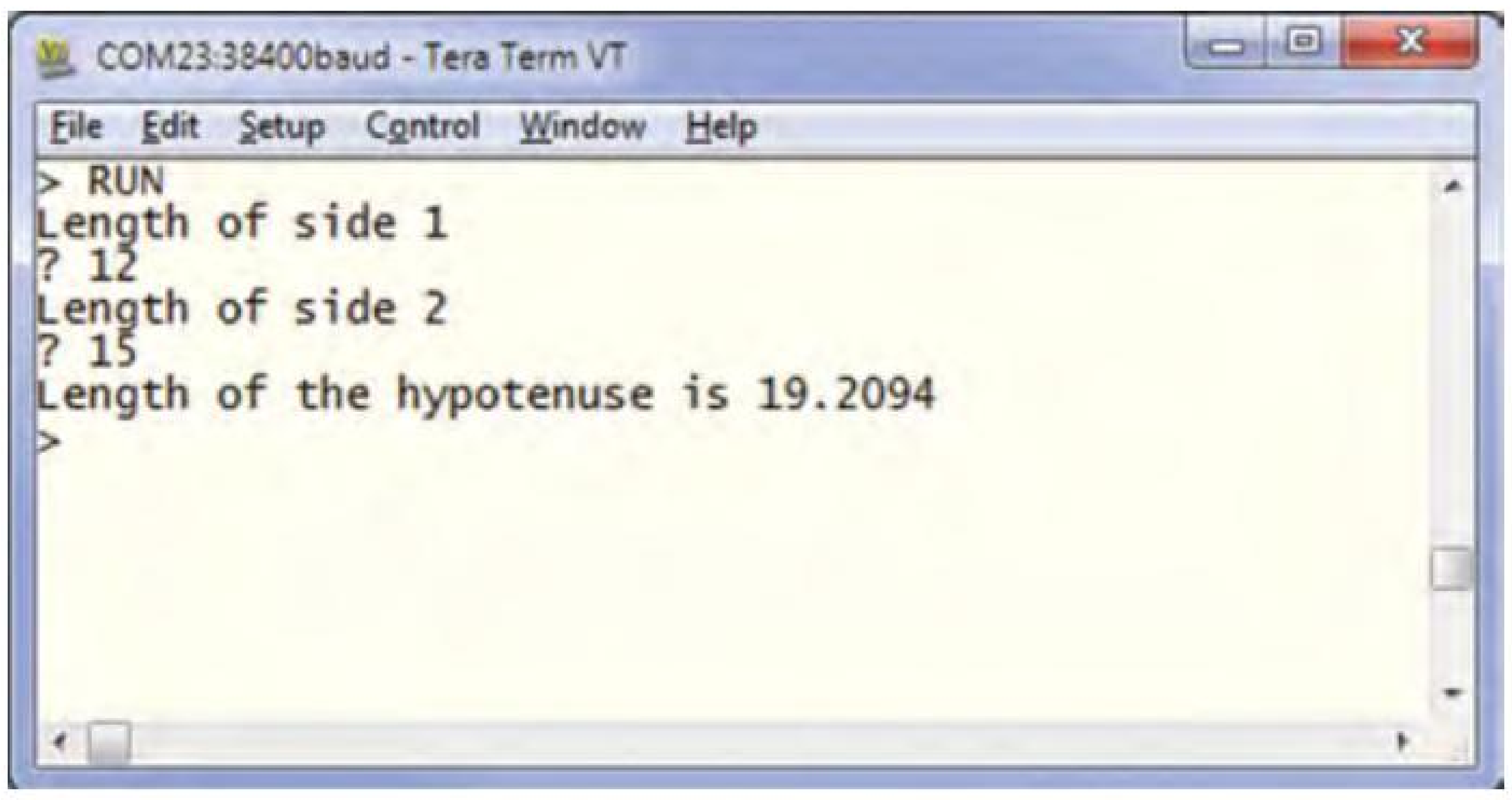
```
INPUT var
```

This command will print a question mark on the console and wait for a number to be entered, followed by the Enter key. That number will then be assigned to the variable var. For example, the following program extends the expression for finding the hypotenuse of a triangle by allowing the user to enter the lengths of the other sides from the console.

```
PRINT "Length of side 1"
```

```
INPUT a
PRINT "Length of side 2"
INPUT b
PRINT "Length of the hypotenuse is" SQR(a * a + b * b)
```

The screen capture of a typical session running this program is shown in Fig.2.



```
> RUN
Length of side 1
? 12
Length of side 2
? 15
Length of the hypotenuse is 19.2094
>
```

COM23:38400baud - Tera Term VT
File Edit Setup Control Window Help

Fig.2. Running a program to calculate the hypotenuse of a triangle

GOTO and labels

One method of controlling the flow of the program is the GOTO command. This essentially tells MMBasic to jump to another part of the program and start executing from there. The target of the GOTO is a label and we will explain them first.

A label is an identifier that marks part of the program. It must be the first thing on the line and it must be terminated with the colon (:) character. The name that you use can be up to 32-characters long and must follow the same rules for a variable's name. For example, in the following program line LoopBack is a label:

```
LoopBack: a = a + 1
```

When you use the GOTO command to jump to that particular part of the program you would use the command like this `GOTO LoopBack`

To put all this into context, the following program will print out all the numbers from 1 to 10:

```
z = 0
LoopBack: z = z + 1
PRINT z
IF z < 10 THEN GOTO LoopBack
```

The program starts by setting the variable z to zero then incrementing it to 1 in the next line. The value of z is printed and then tested to see if it is less than 10. If it is less than 10 the program execution will jump back to the label LoopBack where the process will repeat. Eventually, the value of z will be more than 10 and the program will run off the end and terminate.

Note that a FOR loop can do the same thing (and is simpler) so this example was purely designed to illustrate what the GOTO command can do.

In the past, the GOTO command acquired a bad reputation. This is because when using the GOTO command it is possible to create a program that continuously jumps from one point to another (often referred to as 'spaghetti code') and that type of program is almost impossible for another programmer to understand. With constructs like the multiline **IF** statements the need for the GOTO statement has been reduced and it should be used only when there is no other way of changing the program's flow.

Testing for prime numbers

Listing 1 shows a simple program which brings together many of the programming features we have discussed. The program will first prompt (on the console) for a number and when it has been entered it will test if that number is a prime number or not and display a suitable message.

It starts with a DO LOOP that does not have a condition – so it will continue looping forever. This is what we want, it means that when the user has entered a number, it will report if it is a prime number or not and then loop around and ask for another number.

The way that the user can exit the program (if they wanted to) is by typing the break character (normally CTRL–C).

The program then prints a prompt for the user, which is terminated with a semicolon character. This means that the cursor is left at the end of the prompt for the INPUT command, which will get the number and store it in variable a.

Listing 1. Prime number test

A short program that asks for a number and tests it to see if it is a prime number. It demonstrates many of the standard constructs within MMBasic including **IF** statements, loops and printing.

```
DO
  InpErr:
  PRINT
  PRINT "Enter a number: ";
  INPUT a
  IF a < 2 THEN
    PRINT "Number must be equal or greater than 2"
    GOTO InpErr
  ENDIF

  Divs = 0
  FOR x = 2 TO a/2
    r = a/x
    IF r = FIX(r) THEN Divs = Divs + 1
  NEXT x

  PRINT a " is ";
  IF Divs > 0 THEN PRINT "not ";
  PRINT "a prime number."
LOOP
```

Next, the number is tested. If it is less than 2 an error message will be printed and the program will jump backwards and ask for the number again.

We are now ready to test if the number is a prime number. The program uses a FOR loop to step through the possible divisors, testing if each one can divide evenly into the entered number. Each time it does, the program will increment the variable Divs. Note that the test is done with the function FIX(r) that simply strips off any digits after the decimal point. So, the condition r = FIX(r) will be true if r is an integer (ie, has no digits after the decimal point).

Finally, the program will construct the message for the user. The key part is that if the variable Divs is greater than zero it means that one or more numbers were found that could divide evenly into the test number. In that case the **IF** statement inserts the word 'not' into the output message. For example, if the entered number was 21 the user will see this response:

```
21 is not a prime number.
```

Fig.3 shows the result of running the program and some of the output. You can test this program by using the editor (the EDIT command) to enter it. Using your newly learnt skills you could then have a shot at making it more efficient. For example, because the program counts how many times a number can be divided into the test number it takes a lot longer than it should to detect a non-prime number. The program would run much more efficiently if it jumped out of the FOR loop at the first number that divided evenly.

You could use the GOTO command to do this or you could use the command EXIT FOR – that would cause the FOR loop to terminate immediately (this command was introduced in MMBasic version 5.2).

Arrays

An array is something that you will probably not think of as useful at first glance, but when you do need to use them you will find them very handy indeed.

An array is best thought of as a large number of variables that are created at the same time with each variable being pointed to by a number, which is called the index. An array is created by the `DIM` command, for example: `DIM n(300)`

This created an array of 301 elements. Note that an array starts from zero, so this is why there is an extra element making the total 301. If you want to set element number 100 in this array to (say) the number 876, you would do it this way:

```
n(100) = 876
```

Normally, the index to an array is not a constant number as shown above, but a variable which can be changed to access different array elements.

As an example of how you might use an array consider the case where you would like to record the temperature for each day of the year and, at the end of the year, calculate the overall average. You could use ordinary variables to record the temperature for each day, but you would need 365 of them and that would make your program very unwieldy indeed. Instead, you could define an array to hold the values like this:

```
DIM days(365)
```

Every day you would need to save the temperature in the correct location in the array. If the number of the day in the year was held in the variable `doy` and the maximum temperature was held in the variable `maxtemp` you would save the reading like this:

```
Days(doy) = maxtemp
```

At the end of the year it would be simple to calculate the average for the year:

```
ave = 0
FOR i = 1 to 365
  ave = ave + days(i)
NEXT i
PRINT "Average is:" ave/365
```

This is much easier that adding up and averaging 365 individual variables.

The above arrays are single dimensioned, but you can have multiple dimensions if you wish. For example, if you wished to record the temperature over five years you could dimension the array like this:

```
DIM days(365, 5)
```

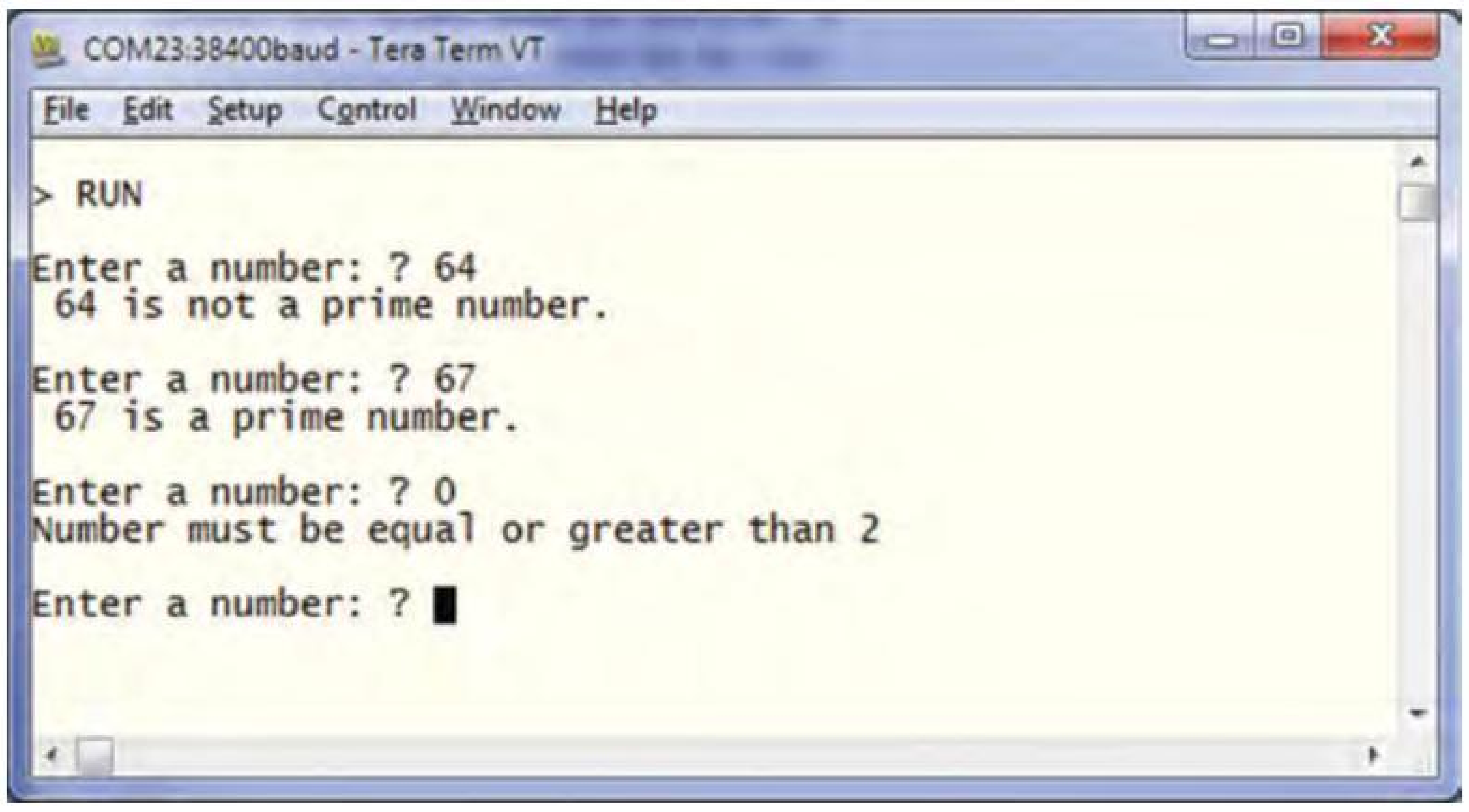
The first index is the day in the year and the second is a number representing the year. If you wanted to set day 100 in year 3 to 24 degrees you would do it like this:

```
days(100, 3) = 24
```

In MMBasic you can have up to eight dimensions and the maximum size of an array is only limited by the amount of free RAM that you have.

Integers

So far, all the numbers and variables that we have been using have been floating point. As explained before, floating point is handy because it will track digits after the decimal point and when you use division it will return a sensible result.


COM23:38400baud - Tera Term VT
File Edit Setup Control Window Help

```
> RUN

Enter a number: ? 64
 64 is not a prime number.

Enter a number: ? 67
 67 is a prime number.

Enter a number: ? 0
Number must be equal or greater than 2

Enter a number: ? █
```

Fig.3. Running the prime number test program

However, the limitation of floating point is that it stores numbers as an approximation with an accuracy of only six or seven digits. For example, if you stored the number 1234.56789 in a floating-point variable and then printed it out you will find that the value stored in the variable is actually 1234.57. Most times this is not a problem, but there are some cases when you want to accurately store large numbers. Examples include tracking a GPS location on the planet's surface and interfacing with digital frequency synthesisers.

As another example, let us say that you want to track time accurately so that you can compare two different date/times to work out which one is earlier. The easy way to do this is convert the date/time to the number of seconds since some date (say 1 Jan 2000) then finding the earliest of the two is just a matter of using an arithmetic compare in an IF statement. The problem is that the number of seconds since that date would far exceed the accuracy range of normal floating-point variables and this is where integer variables come in. An integer variable in MMBasic can accurately hold numbers up to nine million million million (or ±9223372036854775807 to be precise), which is a very large number indeed.

The downside of an integer is that it cannot store fractions (ie, numbers after the decimal point). Any calculation that produces a fractional result will be rounded up or down to the nearest whole number when assigned to an integer.

It is easy to create integer variables, just add the percent symbol (%) as a suffix to a variable name. For example, `sec%` is an integer variable. Within a program you can mix integers and floating point and MMBasic will make the necessary conversions, but if you want to maintain the full accuracy of integers you should avoid mixing the two.

Just like floating-point arrays, you can have arrays of integers with up to eight dimensions, all you need to do is add the percent character as a suffix to the array name. For example: `days%(365, 5)`.

Strings

Strings are another variable type (like floating point and integers). Strings are used to hold a sequence of characters. For example, in the command `PRINT "Hello"`, the string `Hello` is a string constant. Note that in code, string constants are always surrounded by double quotes – `"Hello"`.

String variables names use the dollar symbol ($) as a suffix to identify them as a string instead of a normal floating-point variable and you can use ordinary assignment to set their value. The following are examples (note that the second example uses an array of strings):

```
Greeting$ = "Hello"
Car$(12) = "Volvo"
```

You can also join strings using the plus operator:

```
Word1$ = "Hello"
Word2$ = "World"
Greeting$ = Word1$ + " " + Word2$
```

In which case the value of `Greeting$` will be `"Hello World"`.

Strings can also be compared using operators such as = (equals), <> (not equals) or < (less than); for example:

```
IF Car$(12) = "Audi" THEN PRINT
"German"
```

String handling is one of MMBasic's strengths and there are many ways to join, pull apart and generally manipulate strings using specialised string functions. For example, `INSTR()` will search a string for one or more characters, `MID$()` will extract one part of a string from another and `VAL()` will convert a string of numbers into a value that can be stored in a numeric variable. For the details, refer to the Functions section of the *Micromite User Manual*.

DIM command

We have mentioned the `DIM` command before when defining arrays, but it can also be used to create ordinary variables. For example, you can create a number of string variables like this:

```
DIM STRING Car, Name, Street,
City
```

Note that because we defined these variables as strings using `DIM` we do not need the $ suffix, the definition alone is enough for MMBasic to identify their type. When you use these variables in an expression you also do not need the type suffix; for example: `City = "Paris"`

You can also use the keyword `INTEGER` to define a number of integer variables and FLOAT to do the same for floating point variables. This type of notation can also be used to define arrays; for example:

```
DIM INTEGER seconds(200)
```

The advantage of defining variables in this way is that they are clearly defined (generally at the start of the program) and their type (float, integer or string) is not subject to misinterpretation. You can strengthen this by using the following commands at the very top of your program:

```
OPTION EXPLICIT
OPTION DEFAULT NONE
```

The first tells MMBasic that *all* variables *must* be defined using the DIM command before they can be used. The second specifies that the type of all variables must be specified when they are created.

Why are these commands important? They avoid a common programming error that can happen if you accidently misspell a variable's name. For example, your program might have the current temperature saved in a variable called Temp, but at one point you accidently misspell it as Tmp. This will cause MMBasic to automatically create a variable called Tmp and set its value to zero.

This is obviously not what you want and it will introduce a subtle error that could be hard to find – even if you were aware that something was not right. On the other hand, if you used the OPTION EXPLICIT command at the start of your program MMBasic would refuse to automatically create the variable and instead would throw an error, thereby saving you from a probable headache.

For small, quick and dirty programs, it is fine to allow MMBasic to automatically create variables, but in larger programs you should always disable this feature with OPTION EXPLICIT and OPTION DEFAULT NONE.

When a variable is created it is set to zero for float and integers and an empty string (ie, contains no characters) for a string variable. You can set its initial value to something else when it is created using DIM. For example:

```
DIM FLOAT nbr = 12.56
DIM STRING Car = "Ford", City
= "Manchester"
```

Subroutines

A subroutine is a block of programming code that is contained within a module and can be called from anywhere within your program. It looks like a built-in command within MMBasic and can be used the same.

For example, assume that you need a command that would signal an error by printing a message on the console and then terminate the program. You could define the subroutine like this:

```
SUB ERRMSG
    PRINT "Error detected"
    END
END SUB
```

Then, in your program you use ERRMSG to display the message; for example:

```
IF A < B THEN ERRMSG
```

The definition of the ERRMSG subroutine can be anywhere in the program, but typically it is at the start or end. If MMBasic runs into the definition while running your program it will simply skip over it.

This is fine enough, but it would be better if a more useful message could be printed, one that would be customised every time the subroutine was called. This can be done by passing a string to the subroutine as an 'argument' (sometimes called a 'parameter'). In this case, the definition of the subroutine would look like this:

```
SUB ERRMSG Msg$
    PRINT "Error: " + Msg$
    END
END SUB
```

Then, when you call the subroutine, you can supply the string to be printed on the command line of the subroutine; for example:

```
ERRMSG "Number too small"
```

When the subroutine is called like this the message Error: Number too small will be printed on the console and the program terminated.

Inside the subroutine Msg$ will have the value of Number too small, and it will be concatenated in the PRINT statement to make the full error message.

A subroutine can have any number of arguments that can be float, integer or string, with each argument separated by a comma. Within the subroutine the arguments act like ordinary variables but they exist only within the subroutine and will vanish when the subroutine ends. You can have variables with the same name in the main program and they will be hidden within the subroutine and be different from arguments defined for the subroutine (at the risk of making debugging harder).

Local variables

Inside a subroutine you will need to use variables for various tasks. In portable code you do not want the name you chose for such a variable to clash with a variable of the same name in the main program. To this end you can define a variable using LOCAL within the subroutine. The syntax for LOCAL is identical to the DIM command, this means that the variable can be an array, you can set the type of the variable and you can initialise it to some value.

For example, this is our ERRMSG subroutine, but this time we have extended it to use a local variable for joining the error message strings.

```
SUB ERRMSG Msg$
    LOCAL STRING tstr
    tstr = "Error: " + Msg$
    PRINT tstr
    END
END SUB
```

The variable tstr is declared within the subroutine, which means that (like the argument list) it only exists within the subroutine and will vanish when the subroutine exits. You can have a variable called tstr in your main program and it will be different from the variable tstr in the subroutine. You should always use local variables for operations within your subroutine because they help make the subroutine much more self-contained and portable.

Functions

Functions are similar to subroutines with the main difference being that a function is used to return a value in an expression. For example, if you wanted a function to select the maximum of two values you could define:

```
FUNCTION Max(a, b)
  IF a > b
    Max = a
  ELSE
    Max = b
  ENDIF
END FUNCTION
```

Then you could use it in an expression:

```
x = 21
y = 25
PRINT "The highest number is"
Max(x, y)
```

The rules for the argument list in a function are similar to subroutines. The only difference is that brackets are required around the argument list when you are calling a function (they are optional when calling a subroutine).

To return a value from the function you assign a value to the function's name within the function. If the function's name is terminated with a type suffix (ie, $, % or !) the function will return that type, otherwise it will return whatever the OPTION DEFAULT is set to. As you can see, the function name is used as an ordinary local variable inside the subroutine. It is only when the function returns that the value assigned to the function name is made available to the expression that called it.

Ready to go!

So there you are – you know the basics of how to program and use the Micromite, all you need do now is incorporate it into your next brilliant project.

Keep up to date!

For updates to the Micromite firmware you can visit the author's website at: **http://geoffg.net/micromite.html**.

Another resource is The Back Shed forum where there are many Micromite users who are happy to help newcomers, see: **www.thebackshed.com/forum/Microcontrollers**

NET WORK

by Alan Winstanley

Dell Downloads

WELCOME to this month's *Net Work*, the Internet column written for *EPE* readers. Last month, I described how I added a Dell FP-61001 fingerprint scanner to a Windows PC. It enabled Roboform, my favourite website login manager, to log in securely with just the swipe of a finger. I had struck lucky with the Dell device, bought cheaply on eBay, as it was claimed to be Windows-compatible up to version 10 and despite a struggle I did get it running on my home-brew Windows 7 PC. I gave links pointing to Dell's driver software that worked well with my Asus PC (all versions of the Dell fingerprint scanner software are listed at: **http://downloads.dell.com/Security/**). As a useful tip, Dell customers searching for obscure software or updates might like to try Dell's 'simplified interface' web page at: **http://downloads.dell.com/published/Pages/index.html**. It is a very lengthy list of Dell products, but if you know the product group or model then a way of drilling down to the file area is simply to type 'CTRL + F' to open a search box in your web browser, and try searching the page for keywords.

Biometric readers are readily available on eBay and I stumbled upon a job lot of Dell devices being sold off cheaply that, happily, proved compatible with Roboform. A few of them are still available at the time of writing, but readers should beware of other types being sold by Chinese gadget sites at an attractive price. Some claim to be Windows 2000-XP-Win 7 compatible (only) and there is often a question mark over whether legacy 32-bit drivers will work in a modern 64-bit machine because Windows compatibility mode does not always work. Prices vary wildly, so make sure beforehand that devices will work with your operating system and hardware before you buy.

As a final note on this topic, facial recognition technology is now starting to emerge, with Microsoft promising that Windows Hello will allow password-free secure logins on an expanding range of devices in the future.

Fighting Fitbit

For over half a decade there's been a groundswell of innovation in networkable gadgets and devices that work in harmony with online services, and many latest 'smart' devices and home appliances have network connectivity built in as standard. Even electric toothbrushes are being re-invented for this networking age. Procter & Gamble's Oral-B Genius 9000 toothbrush, for example, uses Bluetooth to connect to a smartphone where an app can be downloaded to give a visual summary of your teeth-cleaning regimen and 'provide focused care as you follow your dental care journey and receive guidance that can be adjusted by your dental professional,' as the Oral-B website gushes.

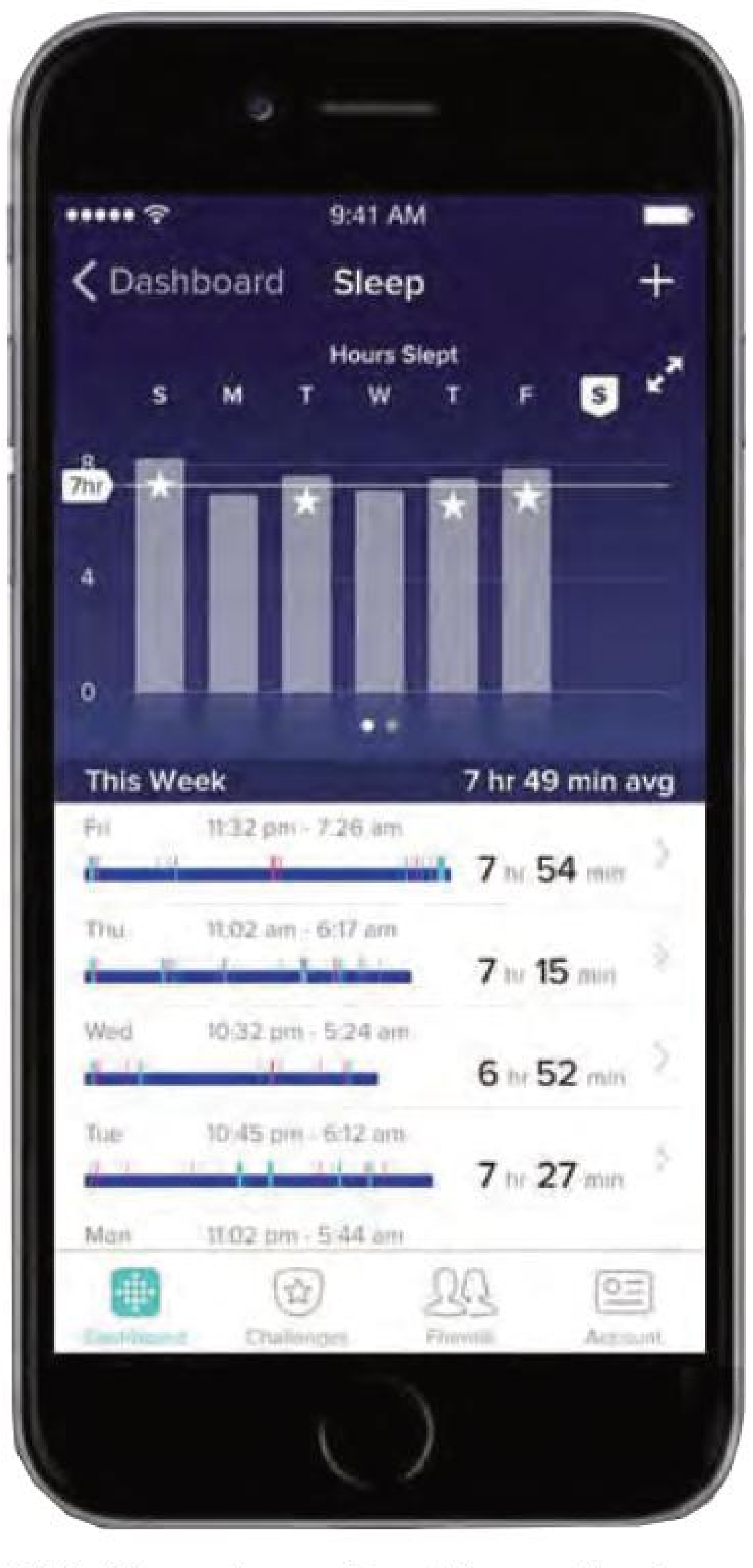
heart rate
96
1:35:59
fitbit

Next-generation 'wearables', such as smart watches and fitness bands are fast becoming useful and affordable after emerging from some tough rounds of funding, as sensor technologies and software evolve but investors try not to get their fingers burnt. However, the very fickle millennial market is becoming saturated with such gadgetry, mirroring the way tablet and smartphone sales have plateaued. Manufacturers can churn them out far more quickly than consumers seek to buy them, and prestigious brands eventually struggle at the hands of cheaper competition.

The Pebble Smartwatch, a major Kickstarter project in 2012 that everyone willed to succeed, was an early effort to link a wristwatch to a smartphone. After two million unit sales, Pebble shuttered the business and sold its intellectual property to Fitbit last December. Fitbit's latest wearables are aimed at those seeking to enhance physical exercise using smart technologies; their sports and designer watches monitor pulse rates, calories burned and elapsed times. Automatic sleep tracking lets a Fitbit wearer check how restful or restless their sleep patterns are, and Fitbit's downloadable app offers a polyunsaturated plethora of data to help users reach their fitness goals.

It is all very on-trend, but selling technology like this in an overcrowded market is perilous, and Fitbit recently announced job cuts totalling 6% and its market valuation has halved in twelve months, according to Bloomberg. Fitbit's press gallery is populated by twenty- and thirty-year olds enjoying perfect health, busily jogging, sprinting, working out or tirelessly pumping iron – you know the sort of thing. Despite Fitbit's clear bias towards the millennial sector, it does offer anyone wanting to get fitter and stay in shape a seamless way of helping with weight loss or exercise. The Fitbit watch captures data (exercise, diet, calories burned, sleep patterns) for everyday activities, sports or hiking, which is passed to a smartphone or tablet to handle the app or get calorific and diet data, and maybe connect to a Wi-Fi weigh scale to log your weight routinely.

As far back as December 2011 I reported on a new generation of LCD bathroom scales from Withings that boasted Wi-Fi interconnectivity, with a blood pressure monitor available as well. Today, Fitbit's Aria bathroom Wi-Fi scale uploads personal readings, including BMI and body fat to the cloud, where it is integrated with the user's Fitbit data. The scales can handle up



Fitbit's sleep-tracking feature enables owners of wrist-worn Fitbits to log their sleep patterns to eight users and Fitbit assure us of complete privacy. Available in black or white, the Aria scales retails at under £100.00, about the same price as Withing's scales.

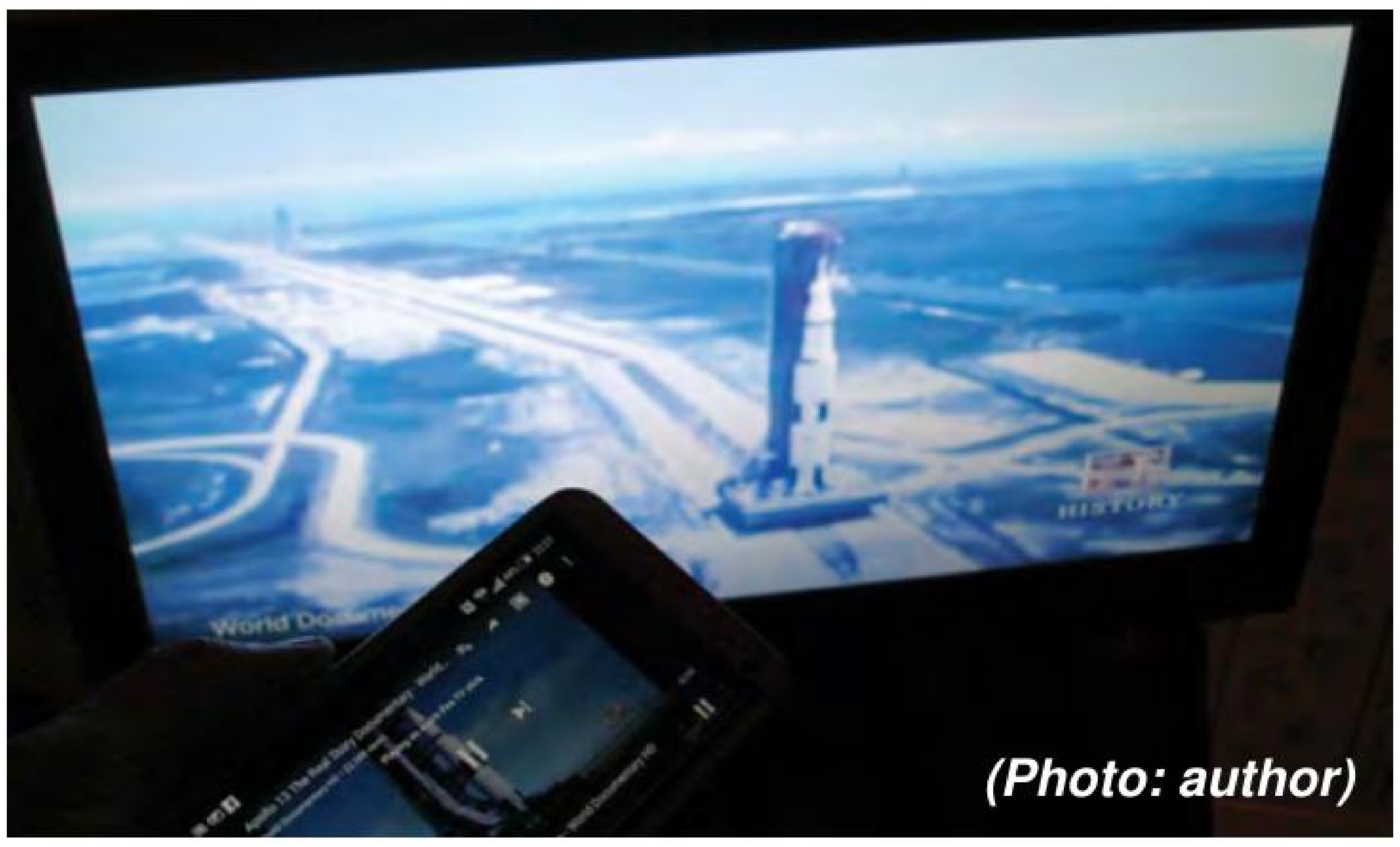
Fitbit would be missing a trick if it failed to reach out (as they call it these days) to older generations of 'silver surfers', or greying ones anyway, who could benefit just as much from this latest smart technology. I asked Fitbit whether they intended to market their technology to appeal to older generations as well as 20-to-30-somethings. There's no answer yet, but in the meantime, the Aria website at **www.fitbit.com/uk/aria** is one I found dreadfully dizzying and clearly aimed at short-attention-span visitors who use a tablet, not a 23-inch PC monitor (the same, it must be said, is true of Withings' website at **www.withings.com**). Fitbit's Zip smart pedometer starts at £50 ($60) while their watches extend to £160 ($190) or so, with some products and prices in between. Fitbit products are available from the usual major UK stores, including Amazon, John Lewis, Very.co.uk and Argos. As early-adopting Pebble owners discovered to their cost, this product sector is far from risk free, and just as tablets and smartphones struggle in a fast-maturing market, more bloodshed will come as fresher, cheaper rivals come to market.

Fire power

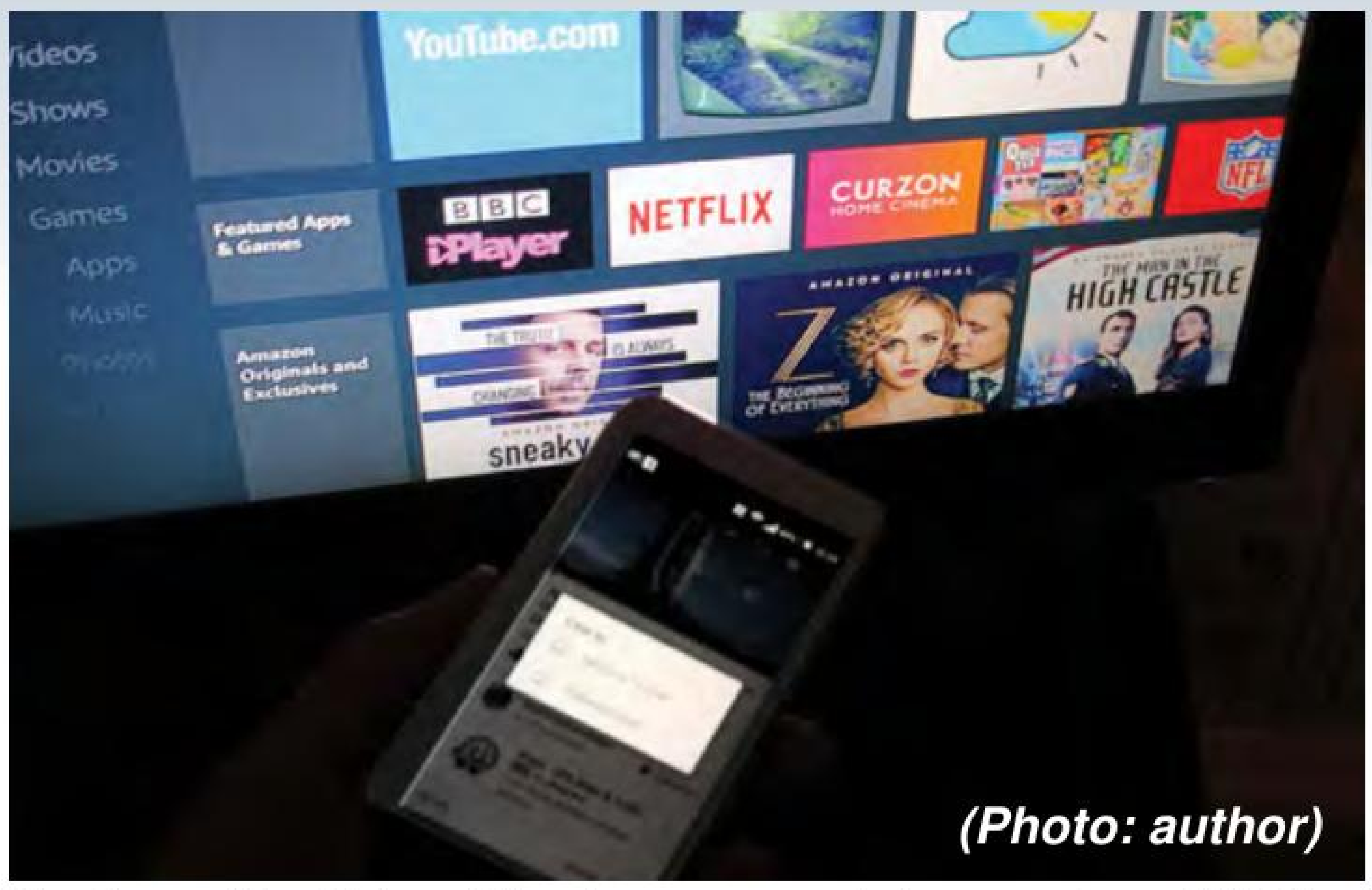
Internet 'smartness' comes as standard with many modern TVs, but maintaining the backwards-compatibility of apps or keeping them up to date is an increasing problem for manufacturers. Barely a week goes by without my Samsung Smart TV updating itself, not that I'm complaining, but I recently tried its YouTube app one more time and rediscovered just how unusable it is. Trying to search for any content is a tortuous process of entering keywords letter by letter using the TV remote control because my Bluetooth keyboard would not work with this YouTube app. A better way is to use a smartphone for searching YouTube, and once found, you can play (cast) the videos onto a networked TV screen. However, I eventually gave up on that idea because, after scanning countless QR codes and typing pairing codes into a website numerous times, pairing no longer seemed to work.

I recently indulged in an Amazon Fire TV Stick, an HDMI dongle that converts an ordinary TV into an altogether smarter one. The Fire TV Stick is heavily biased towards pushing Amazon's paid-for Prime content, but after a decent amount of testing I found that the HDMI dongle and its simple wireless remote control work very well and were easy to live with. It was simple to download some apps, including all the UK catch-up TV channels and BBC iPlayer, followed by the YouTube app. How would this compare with Samsung's Smart TV? The answer became clear when browsing YouTube once again on my Android phone, where it was easy to find video content and queue it up, then cast it onto the Fire-equipped TV, which sprang into life after 30 seconds or so.

This plan almost went without a hitch as I settled back to enjoy a queue of videos and documentaries, until the Fire app locked up! To my disappointment the setup needed rebooting after a few minutes. Perhaps the glitch was caused by a pesky update or a LAN problem, but it has happened once or twice since then, 'dropping the line' inconveniently. A Fire TV Stick can also play slideshows of favourite photos and there are some decent weather apps and screensavers with rainfall to help you nod off to sleep at night. Fire Stick is a useful way of 'going smart' with an HDMI screen or TV and costs £35; it does go on offer from time to time, so keep an eye on the price tag.


(Photo: author)

Videos can be queued on a smartphone for seamless playing on a TV



(Photo: author)

Casting a YouTube video from a smartphone onto a TV fitted with an Amazon Fire TV Stick

YouTube videos now have 'ad breaks' denoted by polite yellow dots along the timeline, so at least users get an advanced warning before an ad rudely bursts onto our screens. It is also a sign of how slick the advertising industry has become, when commercials shown across terrestrial TV also appear online in YouTube, Facebook and everywhere else at the same time.

That's all for this month's *Net Work*. If you have any comments or suggestions, you can email the author at **alan@epemag.net** or send letters for possible inclusion in *Readout* to **editorial@wimborne.co.uk**

CRICKLEWOOD ELECTRONICS
Established 1981

Frustrated with your supplier?
Visit our component packed website for a vast range of parts - old and new, many unavailable elsewhere!
www.cricklewoodelectronics.com

1000's OF PRICES REDUCED!

Alternatively phone us on 020 8452 0161 with your requirements.

Visit our Shop, Call or Buy online at:
www.cricklewoodelectronics.com
020 8452 0161
Visit our shop at:
40-42 Cricklewood Broadway
London NW2 3ET

PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICs and the PICkit 3: LED Binary Clock – Part 2

LAST MONTH, we designed and built the *LED Binary Clock*. Now we need to look at controlling the LEDs to display the time. Before continuing, I recommend looking back at last month's article on what was done and how it was done.

Project planning

First, do re-read the plan (project 'specification') in last month's column before moving onto the software.

We've already covered most of the 'specification'. We have the hardware built and it's ready for programming. From our plan, we now need to show the hours, minutes and seconds accurately. We also need to add the functionality of dimming the LEDs and changing the time.

Project flow

As with any software project, we need to know the flow of the software – from setting up the GPIOs to starting the Timers, the ADC and PWM modules.

In this project, there's a lot going on as we try and incorporate as much of the PICKit 3 Demo Board Tutorials as possible. As discussed last month, we're going to incorporate left/right shifting, analogue-to-digital conversion, debounce, pulse-width modulation and the Timer.

The flow chart is split into two pieces, the main setup and the main while loop. Fig.1 shows the main setup flow chart, which details the flow of setting up our variables, ports, PWM, ADC and Timer before entering the main `while` loop.

Fig.2 shows the main `while` loop flow chart. Fig.2 is clearly more involved and may seem unwieldy, but stick with it and try to understand the details.

Here's an overview of what's happening. The Timer0 runs in the background and once every second it toggles an interrupt flag (`INTCONbits.TMR0IF`). Before this interrupt flag is toggled, the code will only check for a button press (for changing hours and minutes). After the interrupt flag has been toggled, a second has passed and the system needs to change the display of seconds, minutes, tens of minutes and hours. The code toggles the `seconds` LED (D12), showing each second as it passes.

The code now determines what time it is. Just like any ordinary twelve-hour clock, if the number of seconds has reached a full minute, then the minutes count will increment. If the minutes count has reached a full ten minutes, then the tens of minutes count will increment. If the tens `of` minutes count has reached the full hour, then the hours count will increment. Finally, to complete the circle, once the hours count has reached twelve hours, the hours variable will reset to zero.

Main setup code

There isn't space to examine each and every line in detail, but all the concepts have been covered in previous *PICs and the PICkit 3* articles. Have a re-read if you're unsure about anything. The full code for this project can be downloaded from *EPE's* website.

```
int maxseconds = 59;
int maxmins = 9;
int maxtenmins = 5;
int maxhours = 0xB0;
int seconds = 0;
int mins = 0;
int tenmins = 0;
int hours = 0;
int val = 0;
```

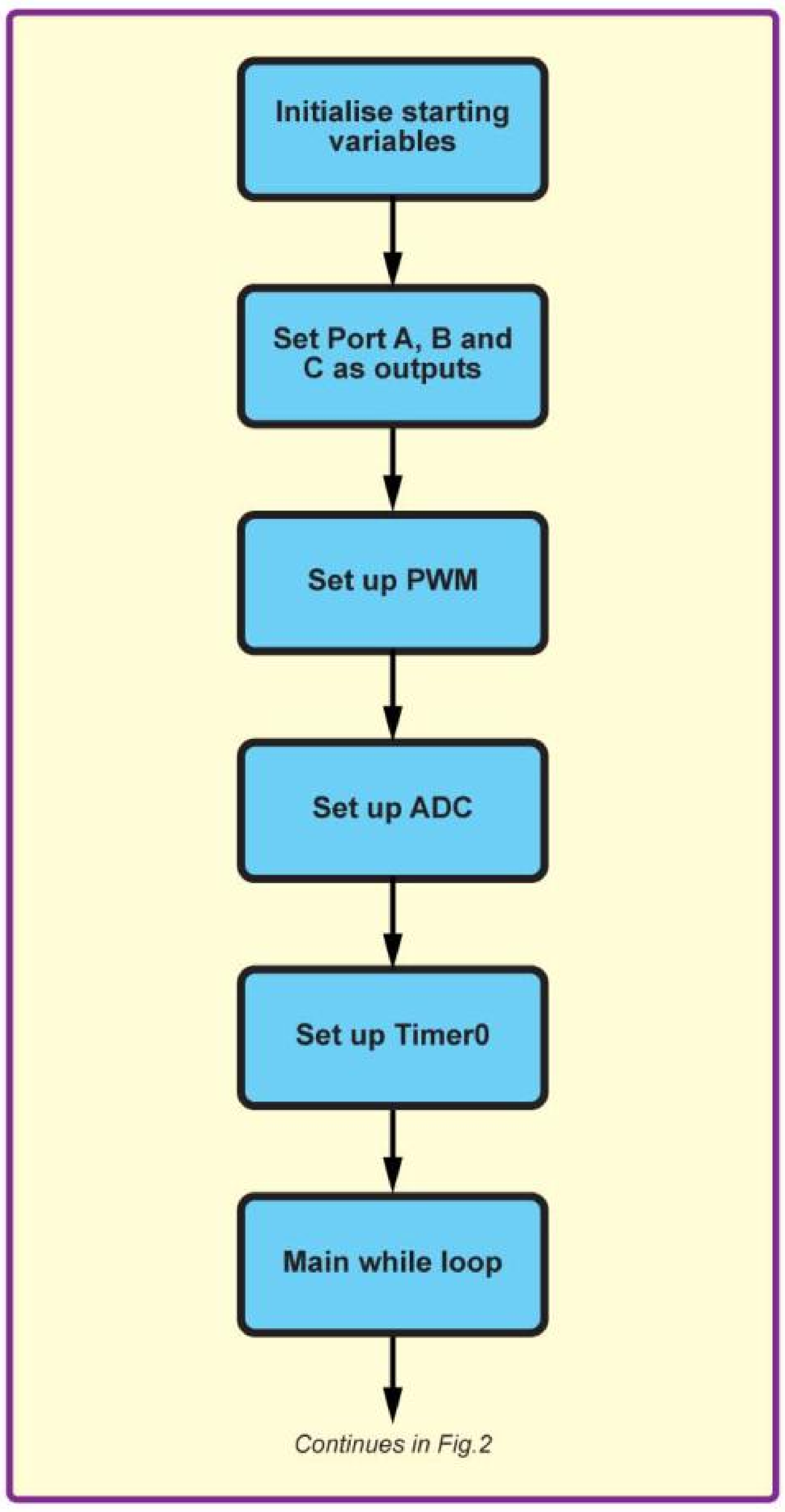


Fig.1. Main setup flow chart

The first thing to set up is the variables used throughout the code. Variables are a handy way of using numbers that will be used often. This also means if we want to change a value, we only need to change it in one place. This method prevents 'hard coding' (using various values throughout the code without using variables, which is a sign of poorly designed, inflexible software). Each variable has a unique and descriptive name; for example, `maxseconds` represents the maximum number of seconds before needing to increment the minutes.

```
OSCCON = 0b00110000;
TRISA = 0;
TRISB = 0;
TRISC = 0;
LATA = 0;
LATB = 0;
LATC = 0;
```

The next thing we want to do is set the internal clock to 250kHz (`OSCCON`), followed by assigning all of PORT A, B and C to outputs (`TRIS`) and then setting them to zero (`LAT`).

```
OPTION_REG = 0b00000111;
```

Next, set the Timer0 register pre-scaler rate to 1:256.

```
CCP1CON = 0b00001100;
PR2 = 255;
CCPTMRSbits.C2TSEL = 0b00;
T2CONbits.T2CKPS = 0b00;
T2CONbits.TMR2ON = 1;
```

These few lines set up the PWM module inside the PIC. This controls transistor TR1, by regulating the connection to ground for the LEDs. The PWM is set to use Port C5 as its output. When the pin is low, the transistor's base is pulled low and so the transistor is turned off, effectively disconnecting the ground from the low side of the LEDs. The pull up (R14) keeps the low side high, thus providing no voltage drop for the LEDs to illuminate. When Port C5 is high, the transistor turns on, connecting ground to the low side of the LEDs and turning them all on. Remember, here we are using PWM, so changing the pulse width varies how long the LEDs are on and thus their average brightness. (Re-read the lesson on PWM for more information on how this works.)

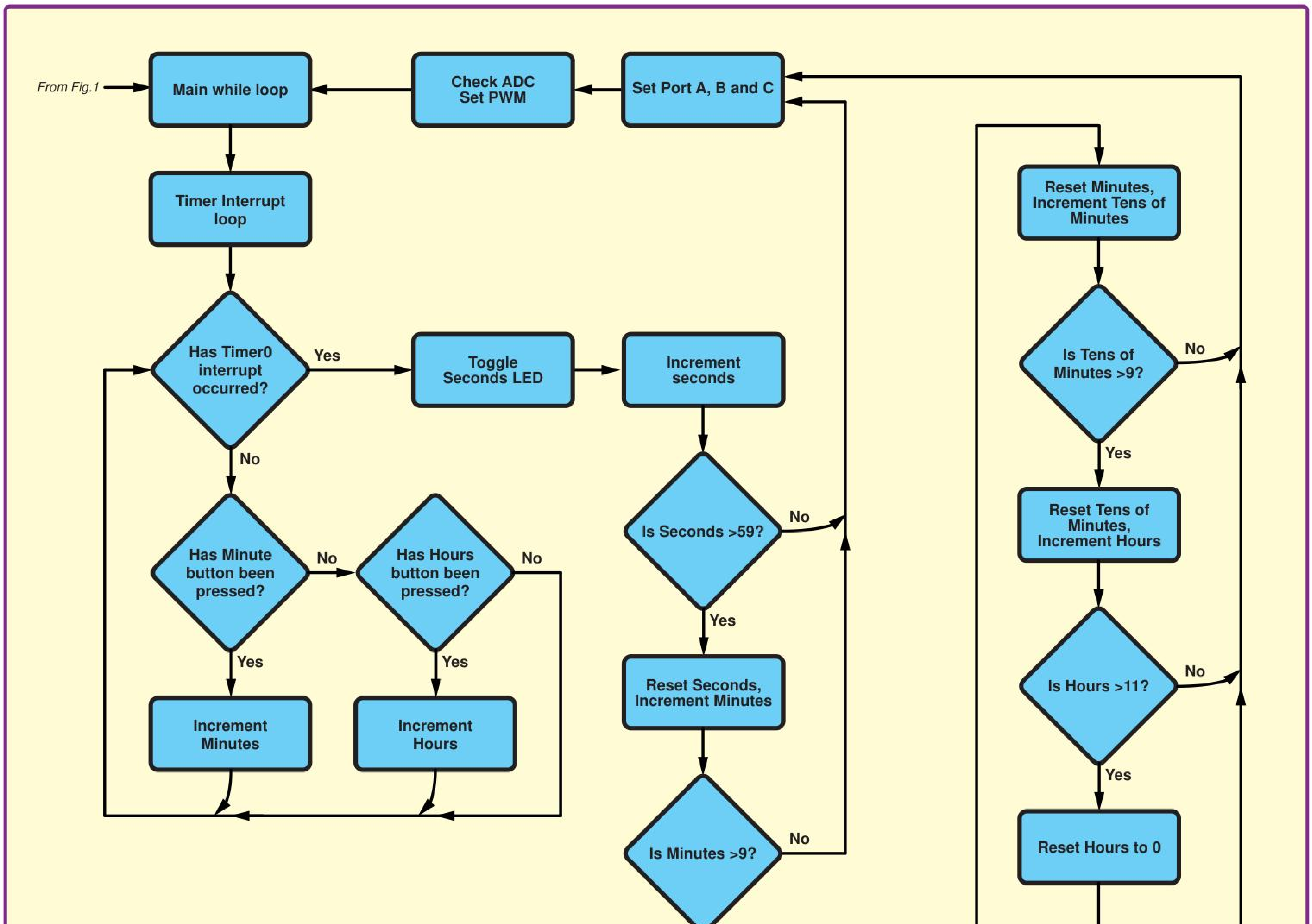

From Fig.1
Main while loop
Check ADC
Set PWM
Set Port A, B and C
Timer Interrupt loop
Has Timer0 interrupt occurred?
Yes
No
Toggle Seconds LED
Increment seconds
Is Seconds >59?
No
Yes
Reset Seconds, Increment Minutes
Is Minutes >9?
No
Yes
Has Minute button been pressed?
No
Yes
Has Hours button been pressed?
No
Yes
Increment Minutes
Increment Hours
Reset Minutes, Increment Tens of Minutes
Is Tens of Minutes >9?
No
Yes
Reset Tens of Minutes, Increment Hours
Is Hours >11?
No
Yes
Reset Hours to 0

Fig.2. Main `while` *flow chart*

```
TRISAbits.TRISA4 = 1;
ANSELAbits.ANSA4 = 0;
TRISAbits.TRISA5 = 1;
```

Next, we need to know how to read the push buttons' status. Ports A, B and C have all been set up as outputs. So now the code sets A4 and A5 as inputs. This is straightforward, but do note that when using port A4, `ANSELAbits.ANSA4 = 0;` has to be used in order to change this pin from its default state as an analogue pin to a digital pin, otherwise the button function won't work.

```
TRISCbits.TRISC7 = 1;
ANSELCbits.ANSC7 = 1;
ADCON0 = 0b00100101;
ADCON1 = 0b00010000;
```

Last but not least, the ADC input. We use the output of this ADC to control the pulse width of the PWM module. Start by setting Port C7 as an input, change it to an analogue input (`ANSELCbits.ANSC7`) and then set AN9 (which is on Port C7) as the ADC input and enable the ADC using the ADCON0 register. To finish, ADCON1 sets the conversion clock select bits.

Main while loop code

Now that the set-up procedure is complete, let's take a look at the main `while` loop code (shown to the right).

First, the `while` loop checks for the Timer0 interrupt flag. The code enters into this `while` loop before performing any other tasks. This piece of code only checks for button presses and increments the `mins`, `tenmins` and `hours` variables if a button press is detected. It cannot exit this loop until the interrupt flag is set high, indicating that a second has passed.

```
while (!INTCONbits.TMR0IF) {
   if (!PORTAbits.RA4) {
      if(mins < maxmins) {
         mins++;
      } else {
         mins = 0;
         if(tenmins < maxtenmins) {
            tenmins++;
         } else {
            tenmins = 0;
         }
      }
      __delay_ms(250);
   }
   if (!PORTAbits.RA5)t {
      if(hours < maxhours) {
         hours = hours + 0x10;
      } else {
         hours = 0;
      }
      __delay_ms(250);
   }
   continue;
}
```

Ports A4 and A5 are the inputs for the minutes and hours buttons. They are normally high. To check if they are high, we could write either `if (PORTAbits.RA5 == 1)` or `if(PORTAbits.RA5)`. Both are valid methods. To check if they are low, we use the `!` sign, which indicates the opposite of the normal state. This can also be written as `if (PORTAbits.RA5 == 0)` or `if(!PORTAbits.RA5)`.

```
INTCONbits.T0IF = 0;
```

Once the loop has been exited, it is necessary to reset the Timer0 interrupt flag:

```
LATCbits.LATC6 ^= 1;
```

The Timer0 interrupt flag has been set and reset, therefore a second has passed. This one line toggles the `seconds` LED (D12). This is not essential for the overall operation of the clock, but it is useful for a project like this because it lets us know the code is working.

After a second has passed and the `seconds` LED is toggled, it's time to alter the seconds, minutes, tens of minutes and hours variables. (See code at the top of the next page). First, the code increments the `seconds` value if it is less than the `maxseconds`

```
if(seconds < maxseconds) {
   seconds++;
} else {
   seconds = 0;
   if(mins < maxmins) {
      mins++;
   } else {
      mins = 0;
      if(tenmins < maxtenmins) {
         tenmins++;
      } else {
         tenmins = 0;
         if(hours < maxhours) {
            hours = hours + 0x10;
         } else {
            hours = 0;
         }
      }
   }
}
```

value (which is 59). Once the `seconds` value has reached 60, a minute has passed, so `seconds` is reset and `minutes` is incremented. Likewise, after 10 minutes: reset the `mins` and increment the `tenmins` variables. And again, when `tenmins` reaches 6: reset `tenmins` and increment `hours`. To finish, when the `hours` variable reaches 12, the clock resets back to zero to start again.

One thing to note here is that `hours` is incremented by `0x10` instead of by 1. This is because the hours LEDs are all on the upper four bits of Port B (B4, B5, B6 and B7) instead of the lower bits of Ports A and C (A0, A1, A2, C0, C1, C2, C3).

```
val = (LATC & 0xF0);
LATC = (val | mins);
val = (LATA & 0xF8);
LATA = (val | tenmins);
val = (LATB & 0x0F);
LATB = (val | hours);
```

This next piece of code is a little more complicated. Here, some Boolean algebra takes the values stored in the `mins`, `tenmins` and `hours` variables and places them straight into Ports A, B and C, which is where our LEDs are connected. The tricky part is that we want to write our values to these ports as easily as possible, without affecting any of the other ports we're using. For example, on Port C, we're using C7 as the ADC input and RC5 as the PWM output. In Port A, we're using A5 and A4 as the button inputs. Writing directly to these registers will disable all of these functions.

In order to perform these assignments correctly, we need to save the value stored in each Port and write only to the pins we're interested in. Looking at the first line (`val = (LATC & 0xF0);`), we use the Boolean operator AND (written as &) to AND the current contents of Port C with 0xF0. The AND function takes two binary digits and its output is a zero, unless *both* digits are 1. Fig.3 shows an example of this AND operation. Notice how everything in the last four digits becomes a zero, while the first four digits are copied. We take the output of this operation and store it in the re-useable variable `val`. This is known as 'bit-masking'; it defines which bits are to be kept and which bits are to be cleared. 0xF0 (11110000) represents the bit-mask for Port C. As only the lower three bits in Port A are used, the bit-mask is 0xF8 (11111000). Port B is different again, as the upper four bits are used, so the bit mask is 0x0F (00001111). The 1 in each case represents the bit we want to keep and a 0 represents the bit we want to clear.

LATC	01010101
0xF0	11110000
OUT	01010000

Fig.3. Example of Boolean AND operation

Next, we want to store this value in Port C using `LATC = (val | mins);`. The symbol | (called 'pipe') is another Boolean operation – OR. Here we OR `val` and `mins`. Fig.4 shows an example of this OR operation. It takes two binary digits and the output is 1 if any of the digits is a 1.

The key thing to note here is the upper four bits of Port C do not change when they are written back. In Fig.3, the upper four bits are 0101 and in Fig.4, the upper four bits are the same again 0101. If we were to write the value in `mins` straight into Port C, these upper four bits would become 0000 and the ADC and PWM would stop working, turning off all of the LEDs.

```
GO = 1;
while (GO) continue;
CCPR1L = ADRESH;
CCP1CONbits.DC1B = (ADRESL>>6);
```

The ADC code here is exactly the same as the code we covered in the Analog to Digital Conversion article back in Part 5 of the *Beginner's Guide*. The code initiates the ADC conversion from port C7. Once it completes, it takes the value ADRESH, stores it in the CCPR1L register to set the pulse width of the PWM. Then we take the value in ADRESL, shift it by six and store the value in the duty cycle.

Download the code from *EPE's* website and use it to program your previously built board and you should now have a working *LED Binary Clock*. Fig.5 shows another version of the clock using blue LEDS instead of red. The veroboard size is wider, but the pinout is the same.

val	01010000
mins	00001001
OUT	01011001

Fig.4. Example of Boolean OR operation

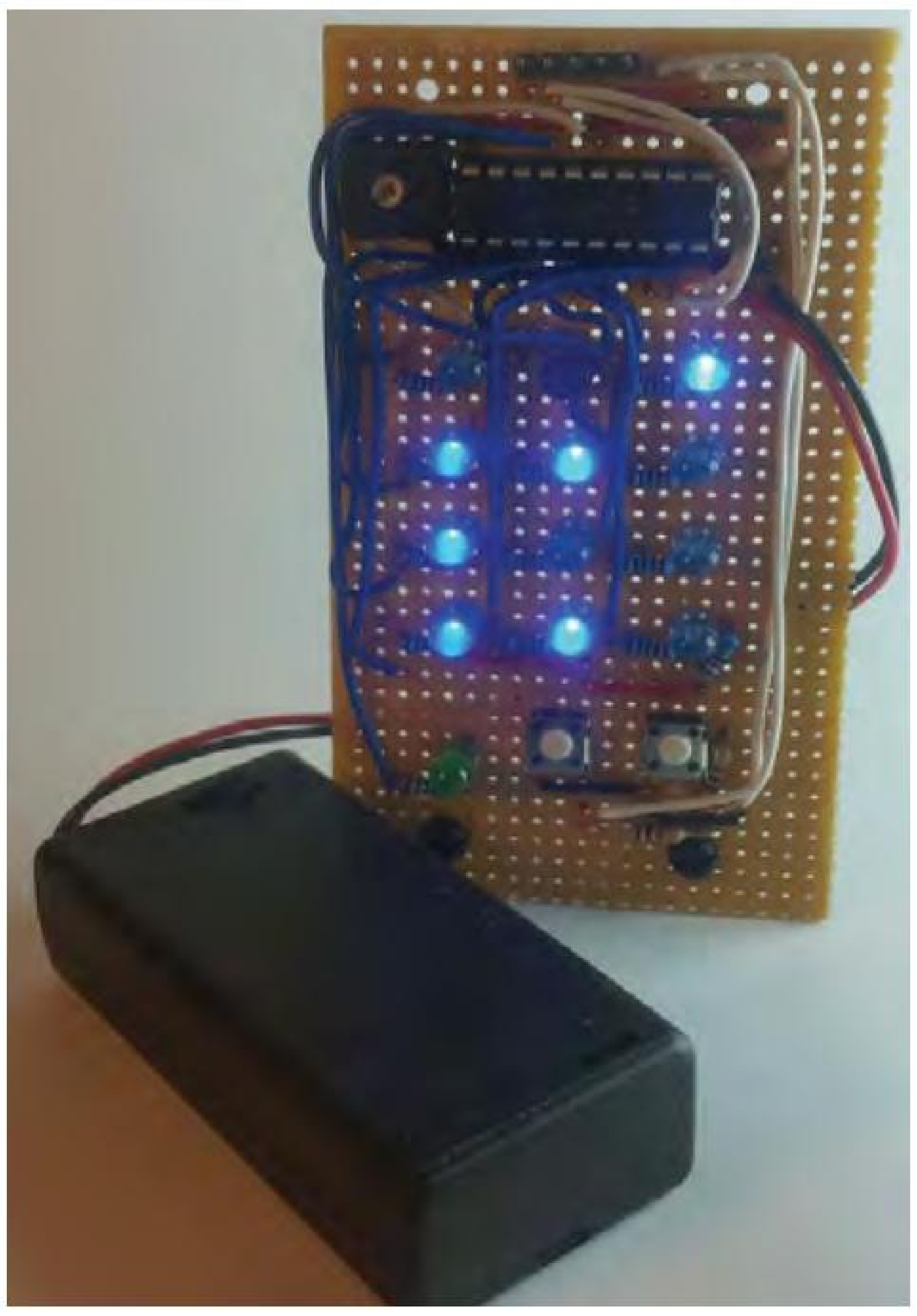


Fig.5. Blue LED Binary Clock

Improvements

Now the project is built and everything hopefully works, so it's a good time to look at how to improve the clock. You may notice after leaving it on for a while that the clock time starts to drift. This is because we're using an internal clock, which is easy to implement, but not the most accurate in the long term. To improve accuracy, we need to add an external 32.768kHz quartz crystal clock to Ports A4 and A5. These are currently being used by the push buttons, so their implementation would need to be changed or removed. Alternatively, we could add a small piece of code to compensate for this time drift, which would act a little like adding a day every leap year to compensate for the fact that a solar year is 365.25 days long.

Mistake on last month's veroboard

One track cut was missing from last month's Fig.4 veroboard layout. The cut needs to be made at coordinate M11. You may notice the board acting strangely without this cut. Omitting it is not going to break anything, but it is necessary for correct operation.

Next month

We're nearing the end of the *Beginner's Guide* using the PICKit 3 Low Pin Count Demo Board. Next month, we'll look at interrupts and pull-ups, which we've touched on over the last two months.

Not all of Mike's technology tinkering and discussion makes it to print.

You can follow the rest of it on Twitter at *@MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

Ingenuity Unlimited

Our regular round-up of readers' own circuits

We pay between £10 and £50 for all material published, depending on length and technical merit. We're looking for novel applications and circuit designs, not simply mechanical, electrical or software ideas. Ideas must be the reader's own work and **must not have been published or submitted for publication elsewhere**. The circuits shown have NOT been proven by us. **Ingenuity Unlimited** is open to ALL abilities, but items for consideration in this column should be word-processed, with a brief circuit description (between 100 and 500 words maximum) and include a full circuit diagram showing all component values. **Please draw all circuit schematics as clearly as possible.** Email your circuit ideas to: **fay.kearn@wimborne.co.uk**.

Your ideas could earn you some cash and a prize!

PicoScope 2000 Series
pico Technology
AWG

WIN A PICOSCOPE 22205A 25MHz USB OSCILLOSCOPE WORTH £159

This PicoScope 2205A Series oscilloscope offers a small, light, modern alternative to bulky benchtop devices. It is perfect for engineers on the move and ideal for a wide range of applications including design, test, education, service monitoring, fault finding and repair. The PicoScope 2205A comes with many great features including: • 2 channels • 25MHz bandwidth • 200MS/s sampling rate • Arbitrary waveform generator • Advanced digital triggers • Persistence display modes • USB connected and powered • Free software upgrades.

Inexpensive DC multi-voltage reference

MY DESIGN is a multilevel, dual polarity, DC variable-voltage reference source of good accuracy. It is based on R-2R networks that form current dividers producing currents that are divided successively by two – see Fig.1. An accurate 5V reference, two precision op amps, each with output transistors are required, along with accurate 20kΩ, 10kΩ and scaling resistors.

R-2R current divider

In the left-hand R-2R network, R4 and R5 are connected in parallel totalling 10kΩ. These are in series with R8 (10kΩ), so the total resistance of the three resistors is 20kΩ. This network is in parallel with R3 (20kΩ) so again we have a total of 10kΩ. Likewise, R7 returns the total to 20kΩ. It should be realised that the successive current flow down each 'vertical' resistor is half the value of the current flow in the 'vertical' resistor to its left. In other words a binary ratio: 8-4-2-1.

Fig.1 shows that the current flowing down R1 from the 5V reference may be switched to ground or to the input of op amp IC1. The feedback resistor connected to this amplifier is calculated to cause the IC1/TR1 output voltage to be –8V for this single switched value of current. If now R3 is switched to feed the op amp, then its current will also flow into the summing point of the op amp. The output voltage will now be –10V. The state of the four switches (S1-4) in this section can be chosen to give a range of –1V to –15V in 1V steps.

Multiple stages

I have designed the circuit to be set up as a two or three-stage BCD (binary-coded decimal) system. My design will

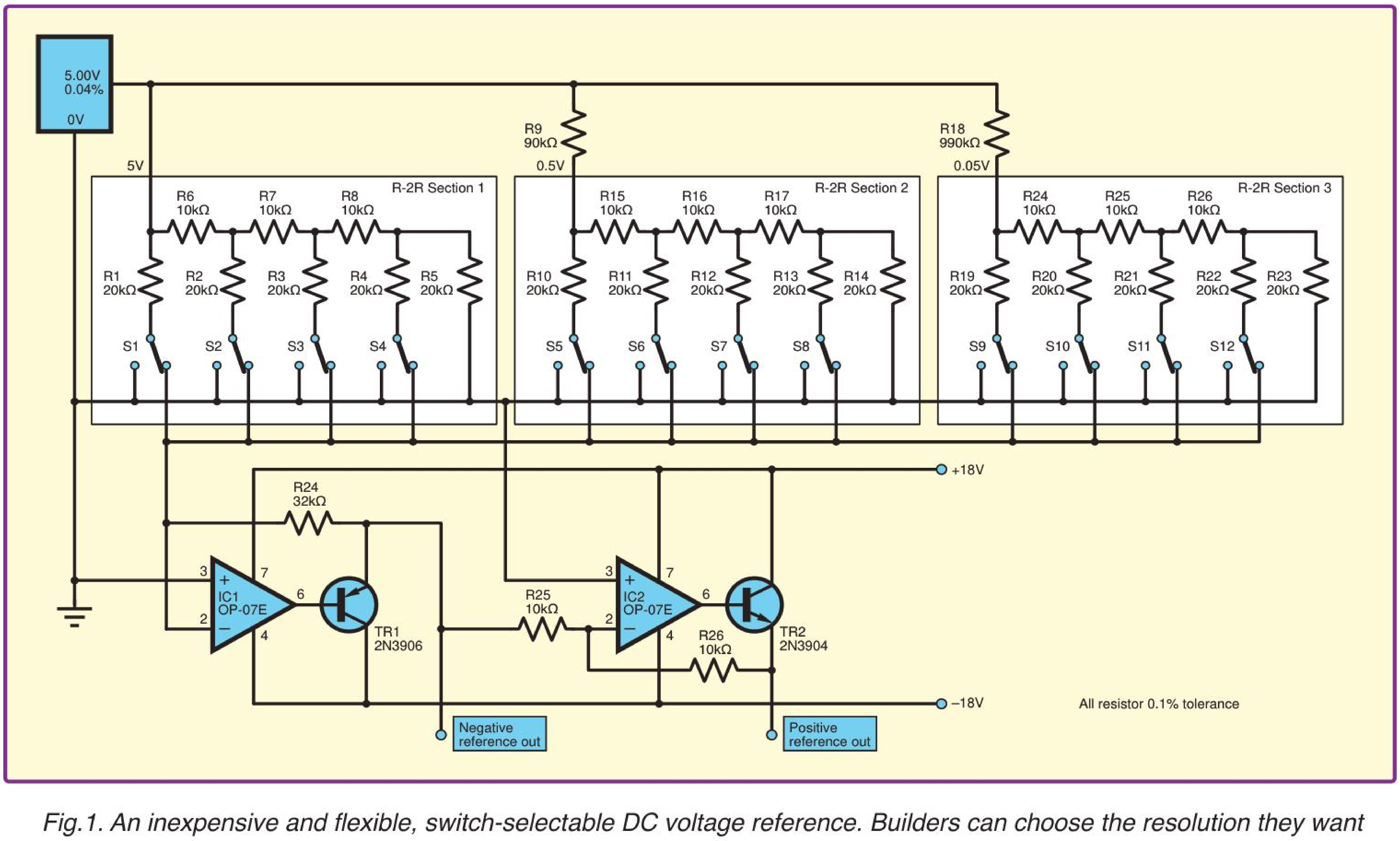

5.00V
0.04%
0V
5V
R9 90kΩ
0.5V
R18 990kΩ
0.05V
R-2R Section 1
R-2R Section 2
R-2R Section 3
R6 10kΩ
R7 10kΩ
R8 10kΩ
R15 10kΩ
R16 10kΩ
R17 10kΩ
R24 10kΩ
R25 10kΩ
R26 10kΩ
R1 20kΩ
R2 20kΩ
R3 20kΩ
R4 20kΩ
R5 20kΩ
R10 20kΩ
R11 20kΩ
R12 20kΩ
R13 20kΩ
R14 20kΩ
R19 20kΩ
R20 20kΩ
R21 20kΩ
R22 20kΩ
R23 20kΩ
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
+18V
R24 32kΩ
3
7
6
2
4
IC1 OP-07E
TR1 2N3906
R25 10kΩ
IC2 OP-07E
R26 10kΩ
TR2 2N3904
–18V
All resistor 0.1% tolerance
Negative reference out
Positive reference out

Fig.1. An inexpensive and flexible, switch-selectable DC voltage reference. Builders can choose the resolution they want

give voltages between ±15V down to ±0.1V for a two stage, or ±0.01V for a three-stage circuit. These stages are supplied via their own series resistor: R9 is 90kΩ and R18 is 990kΩ.

The second R-2R section, identical to the first, is fed from the 5V reference as described, such that the voltage at its input is 0.5V. Subsequent action of its switches will then produce steps of 0.1V per minor step, adding to the voltage from the first stage. A third identical R-2R section, with series resistor R18, will then supply 0.01V per minor step.

The negative voltages set up by IC1/TR1 are inverted by op amp IC2/TR2, to give the equivalent positive reference voltages. These supplies are capable of supplying up to 20mA each.

Ivan Eamus, Ashwell, Rutland

Steam train sound simulator

PRACTICAL applications for this circuit are most likely to be found among members of the model railway community, but the design should also be of interest to general electronics enthusiasts.

This circuit simulates the sound of a steam train, a sound that should be very familiar to the older section of *EPE's* readership. So, if you would like to enhance your model railway layout with some sound effects than building this design could be for you.

The circuit will simulate both slow and fast-moving steam trains, with an option to turn the sound effect off if required. In addition, at the push of a button, a constant steam sound can be generated, simulating the constant venting of steam which can occur while a train is standing in a station.

Noisy diodes

The noise-generating property of zener diodes is put to good use in this circuit – one is used as a white-noise generator for the very realistic steam sound simulation. Some zener diodes of the specified type (BZX85C-12V0) produce a louder circuit output than others of the same type. I bought and tested several of these devices in-circuit, and then selected the particular diode that gave the best results.

Zener diode D1, the noise generator is biased just into conduction by R1, a 100kΩ resistor. The noisy output of the zener is applied to the input of a two-stage amplifier, which is based around IC1 and dual operational amplifier NE5532. The voltage supply for the circuit is 24V DC and the particular zener diode used is a 12V variant, the non-inverting input to IC1a is conveniently biased to about mid-supply.

IC1a is configured as a non-inverting AC amplifier. (The inclusion of DC-blocking capacitor C3 converts the amplifier based around IC1a from a DC amplifier into an AC one.) The gain of this amplifier is 48 (calculated from1+R3/R2).

IC1a's output is fed to volume control potentiometer VR1 and then to the following inverting amplifier based around IC1b. The necessary AC coupling is implemented either side of VR1 by the action of C2 and C9. IC1b's non-inverting input is biased to mid-supply by R5 and R6. The amplifier has a gain of –20 (calculated from –R7/R4).

These two cascaded gains result in a combined gain of –960. The output signal from IC1b is applied to the push-pull current-boosting stage comprised of TR1 and TR2, which are required to drive the low-impedance load of the loudspeaker.

This push-pull output stage has a voltage gain of a little under unity. The amplified white-noise signal is coupled to the loudspeaker by AC-coupling capacitor C4, which is required because the circuit operates from a single voltage supply. Without C4 there would be a standing DC voltage across the loudspeaker, which some loudspeaker types can't tolerate.

Chuff-chuff!

So far, I have described the amplification of the continuous output from a white-noise source and the resulting signal's application to a loudspeaker. In order to turn the signal on and off to simulate the 'chuff-chuff' sound of a steam train,

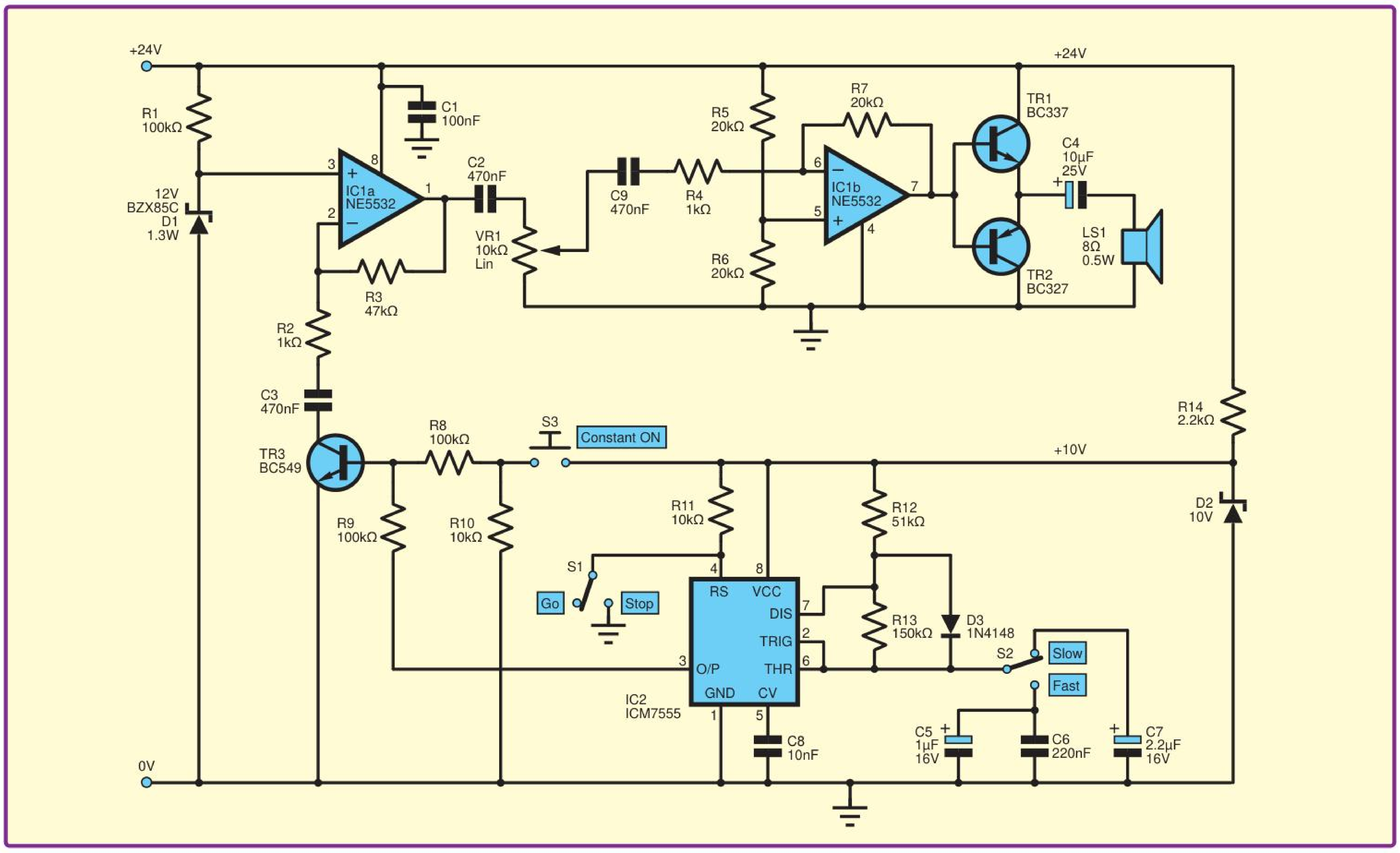


Fig.2. Add some audio realism to your model train layout with this steam train simulator

I have included a 7555 timer operating in astable mode. Its output switches transistor TR3 on and off. (A 7555 timer is a low-power CMOS version of the standard 555 timer.)

When the 7555's output goes low, it turns TR3 off, which has the effect of reducing the gain of IC1a to unity thereby vastly decreasing the amplitude of the white-noise signal and silencing the loudspeaker. When the 7555's output goes high, TR3 is turned on and the full gain of IC1a is restored. This particular method, used for turning the signal on and off, works very well and avoids rapidly charging/discharging any of the AC coupling capacitors, which would cause clicks to be emitted from the loudspeaker. TR3 can be turned on constantly by pressing momentary-action push-to-make switch S3, thus simulating a train venting steam while it is stationary in the station. The sound output can also be turned off if required with the aid of S1, which, when operated, pulls the re-set pin of the 7555 to ground resulting in its output (pin 3) being held at 0V.

Adjustments

Diode D3 is included in the design to enable the independent adjustment of the mark or space times of the 7555's output signal by varying the value of resistors R12 or R13 respectively. This keeps things simple when making adjustments to component values and also enables a waveform with a duty cycle of 50% or less to be generated, something that isn't possible without the diode in place. Varying R12 or R13 therefore adjusts both the duty cycle and the frequency of the 7555's output.

To vary just the frequency of the 7555's output waveform (keeping the duty cycle constant) adjust the value(s) of C5 and C6 or C7. What this means is that if the duty cycle of the output sound is to remain as set, a circuit builder can adjust the simulated speed of a train by varying just the size of the timing capacitors C5 and C6 and/or C7 to his or her own requirements. A facility has been included in the design to switch between fast-train and slow-train simulations by operating S2.

The 24V power supply is too high a voltage to power a 7555 timer and so a lower 10V rail (no pun intended!) is generated by the combination of R14 and D2. This circuit can be conveniently powered by a 24V DC output, mains-driven plug pack.

Chris Hinchcliffe, Dorset

WIN A PICOSCOPE 22205A 25MHz USB OSCILLOSCOPE WORTH £159

If you have a novel circuit idea which would be of use to other readers, then a Pico Technology 22205A 25MHz USB Oscilloscope could be yours.

After every 20 published IU circuits, the best entry will be awarded a Series oscilloscope worth £159.

Laser

Why tolerate when you can automate?

X-10 *Home Automation*

KAT5 AV transmission and IR control system

Barix Ethernet based MP3, communications and control systems

www.laser.com

Integrators, Installers, Trade and Retail customers welcome

C-Bus Shop

C-Bus and C-Bus Wireless

www.cbus-shop.com

Laser Business Systems Ltd
Tel: +44 (0) 20 8441 9788
Fax: +44 (0) 20 8449 0430
Email: info@laser.com
16 Garthland Drive, EN5 3BB

HP 34401A Digital Multimeter 6 ½ Digit

HP 54600B Oscilloscope Analoque/Digital Dual Trace 100MHZ

LAMBDA GENESYS	PSU GEN100-15 100V 15A Boxed As New	£325
LAMBDA GENESYS	PSU GEN50-30 50V 30A	£325
HP34401A	Digital Multimeter 6.5 digit	£275-£325
HP33120A	Function Generator 100 microHZ-15MHZ	£260-£300
HP53131A	Universal Counter 3GHZ Boxed unused	£500
HP53131A	Universal Counter 225MHZ	£350
HP54600B	Digital Oscilloscope 100MHZ 20MS/S	from £75
IFR 2025	Signal Generator 9kHz - 2.51GHZ Opt 04/11	£900
Marconi 2955B	Radio Communications Test Set	£800
R&S APN62	Syn Function Generator 1HZ-260KHZ	£195
Fluke/Philips PM3092	Oscilloscope 2+2 Channel 200MHZ Delay etc	£250
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
HP6032A	PSU 0-60V 0-50A 1000W	£750
HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
HP6624A	PSU 4 Outputs	£350
HP6632B	PSU 0-20V 0-5A	£195
HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHZ-20GHZ	£2,000
HP83731A	Synthesised Signal Generator 1-20GHZ	£1,800
HP8484A	Power Sensor 0.01-18GHZ 3nW-10uW	£75
HP8560A	Spectrum Analyser Synthesised 50HZ - 2.9GHZ	£1,250
HP8560E	Spectrum Analyser Synthesised 30HZ - 2.9GHZ	£1,750
HP8563A	Spectrum Analyser Synthesised 9KHZ-22GHZ	£2,250
HP8566B	Spectrum Analsyer 100HZ-22GHZ	£1,200
HP8662A	RF Generator 10KHZ - 1280MHZ	£750
Marconi 2022E	Synthesised AM/FM Signal Generator 10KHZ-1.01GHZ	£325
Marconi 2024	Synthesised Signal Generator 9KHZ-2.4GHZ	£800
Marconi 2030	Synthesised Signal Generator 10KHZ-1.35GHZ	£750
Marconi 2305	Modulation Meter	£250
Marconi 2440	Counter 20GHZ	£295
Marconi 2945	Communications Test Set Various Options	£2,500
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHZ-20GHZ	£1,950
Marconi 6200B	Microwave Test Set	£2,300
Marconi 6960B with	6910 Power Meter	£295

MARCONI 2955B Radio Communications Test Set

FLUKE/PHILIPS PM3092 Oscilloscope 2+2 Channel 200MHZ Delay TB, Autoset etc

Tektronix TDS3012	Oscilloscope 2 Channel 100MHZ 1.25GS/S	£450
Tektronix 2430A	Oscilloscope Dual Trace 150MHZ 100MS/S	£350
Tektronix 2465B	Oscilloscope 4 Channel 400MHZ	£600
Cirrus CL254	Sound Level Meter with Calibrator	£40
Farnell AP60/50	PSU 0-60V 0-50A 1KW Switch Mode	£195
Farnell H60/50	PSU 0-60V 0-50A	£500
Farnell B30/10	PSU 30V 10A Variable No Meters	£45
Farnell B30/20	PSU 30V 20A Variable No Meters	£75
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell LF1	Sine/sq Oscillator 10HZ-1MHZ	£45
Racal 1991	Counter/Timer 160MHZ 9 Digit	£150
Racal 2101	Counter 20GHZ LED	£295
Racal 9300	True RMS Millivoltmeter 5HZ-20MHZ etc	£45
Racal 9300B	As 9300	£75
Black Star Orion	Colour Bar Generator RGB & Video	£30
Black Star 1325	Counter Timer 1.3GHZ	£60
Ferrograph RTS2	Test Set	£50
Fluke 97	Scopemeter 2 Channel 50MHZ 25MS/S	£75
Fluke 99B	Scopemeter 2 Channel 100MHZ 5GS/S	£125
Gigatronics 7100	Synthesised Signal Generator 10MHZ-20GHZ	£1,950
Panasonic VP7705A	Wow & Flutter Meter	£60
Panasonic VP8401B	TV Signal Generator Multi Outputs	£75
Pendulum CNT90	Timer Counter Analyser 20GHZ	£750
Seaward Nova	PAT Tester	£95
Solartron 7150	6 1/2 Digit DMM True RMS IEEE	£65
Solartron 7150 Plus	as 7150 plus Temp Measurement	£75
Solatron 7075	DMM 7 1/2 Digit	£60
Solatron 1253	Gain Phase Analyser 1mHZ-20KHZ	£600
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160-£200
Thurlby TG210	Function Generator 0.002-2MHZ TTL etc Kenwood Badged	£65

STEWART OF READING
17A King Street, Mortimer, near Reading, RG7 3RS
Telephone: **0118 933 1111** Fax: **0118 9331275**
USED ELECTRONIC TEST EQUIPMENT
Check website **www.stewart-of-reading.co.uk**

CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Variable voltage PWM

FREQUENT *EPE Chat Zone* contributor ***noel*** asked about achieving a variable-voltage pulse width modulation (PWM) control for a load, with the PWM switching signal originating from a microcontroller. This is a little unusual, typically the voltage applied when using PWM to control a load is fixed; the whole point being that it is easier to control the power to the load by digital switching than by analogue voltage or current control. We do not know ***noel's*** exact application or load requirements, but we can imagine a system which might need to handle a variety of loads at different voltages (maybe for test, evaluation or experimentation), so it is a legitimate design problem. ***noel*** describes his circuit as follows.

'I have a circuit where I am controlling a PWM current through a load using a PWM signal (0-5V) generated by a PIC16F84A. I need to add some bias to the PIC output so that the PWM signal amplitude can be varied between 0 and 5V.'

There was an issue with ***noel's*** original circuit, in that the PIC output could become shorted to the supply when the voltage-control potentiometer was at one end of its scale. A solution was posted by *Chat Zone* user ***dave_g*** (see Fig.1), which is very close to ***noel's*** original approach but avoided the short-circuit issue. The circuit varies the amplitude of the PWM signal from the microcontroller into the base of the load-switching transistor. The question is, 'how well does this circuit perform?' ***dave_g*** pointed out disadvantages of this approach in terms of potential power dissipation in the transistor and the possible effects of variable transistor gain.

In this article we look at the performance of the circuit in Fig.1 in detail using simulation. Before that, we will discuss PWM in general, particularly with respect to load power control. We discussed transistor switching in a recent issue (February 2017) so we will not repeat all the basics here. Readers unfamiliar with terms such as transistor saturation, forced beta and forward active operation may benefit from reading that article first. However, please note that there was an error in table 1 in that article, which was corrected in following issue.

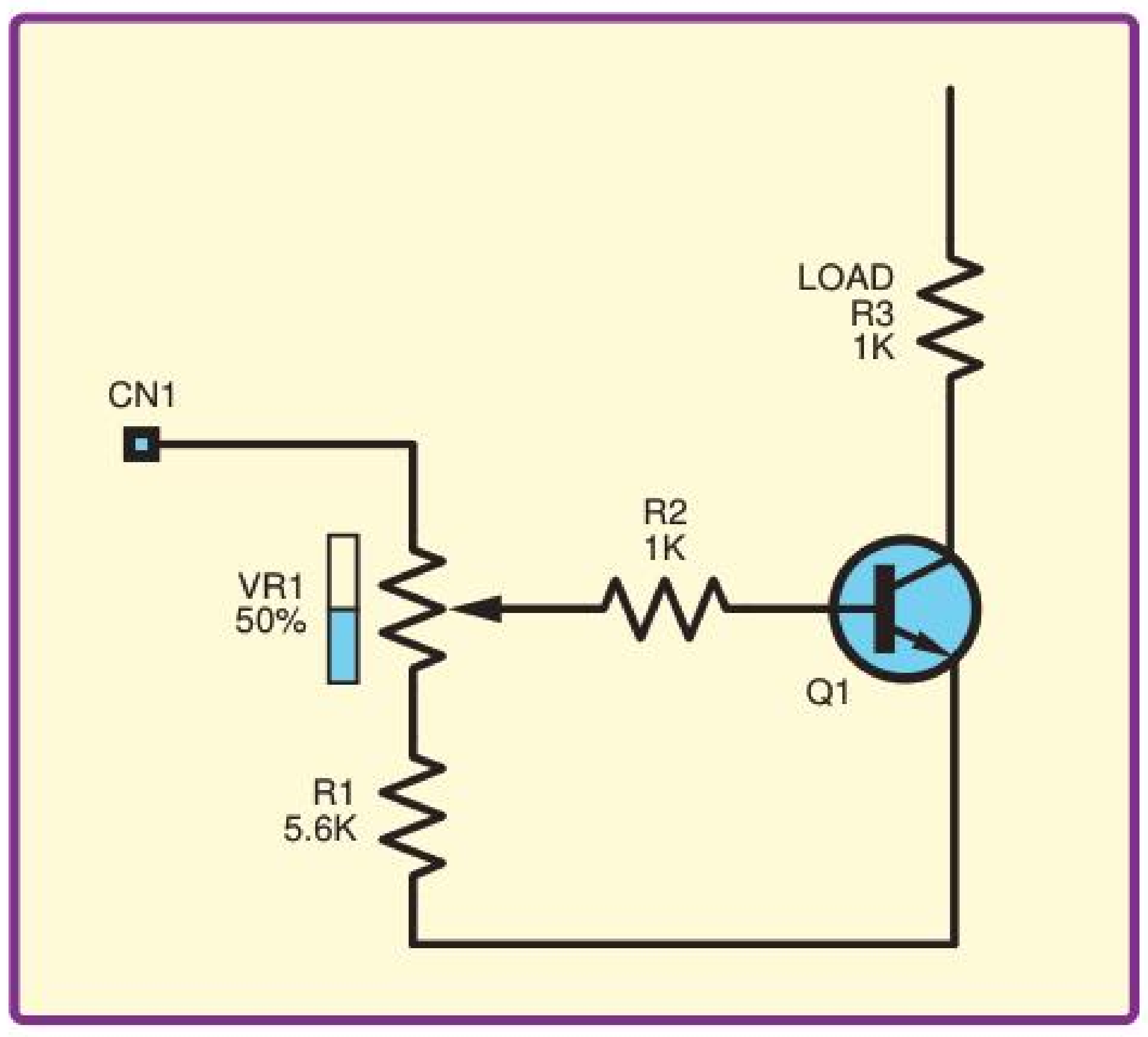


Fig.1. ***dave_g's*** *version of* ***noel's*** *variable-voltage PWM circuit (from* EPE Chat Zone*)*

PWM basics

PWM is used in a wide variety of applications including switch-mode power supplies, the control signals sent to radio-control servos, class D amplifiers and power delivery control. It is the latter which we assume is the purpose of ***noel's*** circuit, so we will focus on this application of PWM. The basic idea in PWM power delivery control is that a continuous sequence of pulses of fixed voltage (or current) is delivered to the load. The width of the pulses can be varied, as indicated by the name, 'pulse width modulation'.

The pulses are typically arranged to switch sufficiently fast so that it is best not to think of the load as switching on and off with each pulse, but instead as receiving an amount of energy (with each pulse) which is proportional to the width of the pulse (assuming fixed voltage). The load power is determined by the average rate at which energy is delivered by the pulses. Typically, the load itself low-pass filters the pulses to provide the averaging function. An example of this is applying power to a heating element where the element and/or the item being heated has a thermal time constant much longer than the pulse duration. If the self-averaging of the load is insufficient then electronic filters can be used, as in switch-mode power supplies.

PWM is commonly used to control LED brightness. This can be for straightforward dimming of LED lights but can also be used to manipulate perceived colour by controlling the relative intensity of closely spaced red, green and blue LEDs in the same package or housing. The LEDs are actually able to switch on and off with the PWM pulses and the averaging processing occurs within the observer due to persistence of vision. More specifically, the PWM pulses to the LED must be faster than the flicker fusion frequency, which is the frequency at which a modulated light source appears to have constant intensity to a human observer.

The waveforms in Fig.2 illustrate the process of averaging a PWM signal. The constant frequency (1kHz) and voltage (1V) pulse waveform (red trace) starts with a 25% duty cycle (the pulse is 1V for 25% of the time and 0V for 75% of the time). After 30ms the duty cycle increases to 50% (equal on and off times) and at 60ms it increases to 75%. The other trace (blue) shows an average value obtained by low-pass filtering the pulse waveform. This represents the power delivered to the load in a PWM power control system.

Averaging

As can be seen in Fig.2, when the PWM duty cycle changes the averaging process means that it takes a while for the power level to settle to the new value. There is also a very small amount of ripple in the power level with each pulse (in Fig.2). The exact waveforms in a real system will depend on the properties of the filtering process, whether this is inherent in the load or is provided by filter circuitry. Fig.2 is for illustrative purposes only and does not aim to represent a specific system.

PWM has the potential to provide very efficient power control, that is, the vast majority of power used is delivered to the load rather than being dissipated in the controlling circuit. In Fig.1, power to the load is controlled by a bipolar transistor acting as an on/off switch driven by the PWM pulses on the CN1 input. If the transistor had zero on resistance, infinite off resistance (no leakage current) and did not require any base current to switch on the circuit then it would be extremely efficient. Real transistors do not achieve this perfection, but high efficiencies are possible. Power losses also occur during the switching process.

The base current is an issue; to achieve saturation when the transistor is on, a reasonably high base current will be needed. Saturation ensures that the voltage drop across the

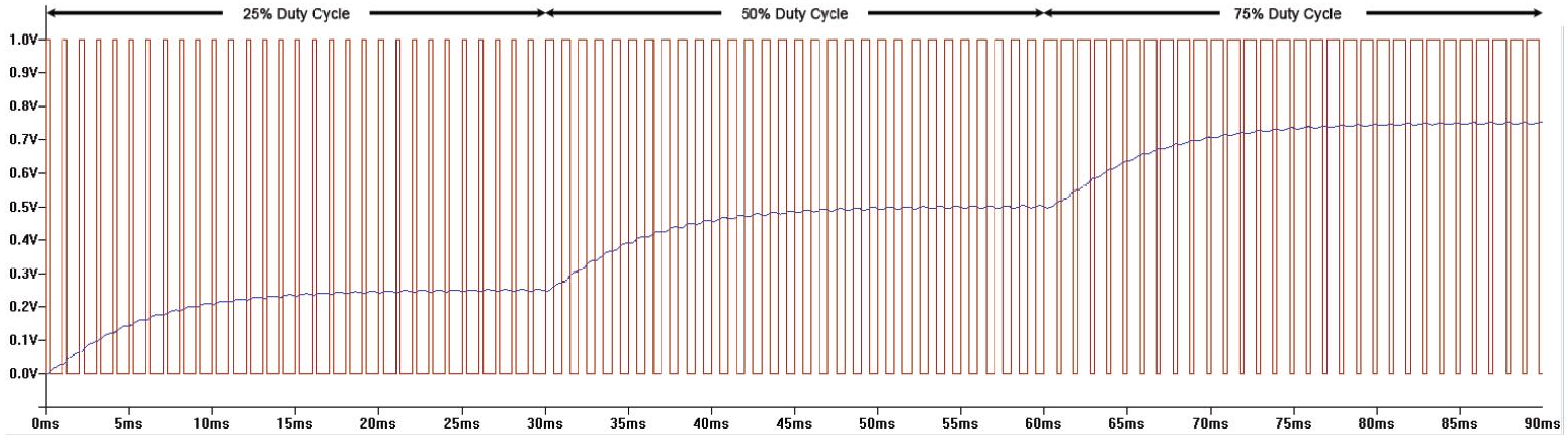


Fig.2. Example PWM waveform

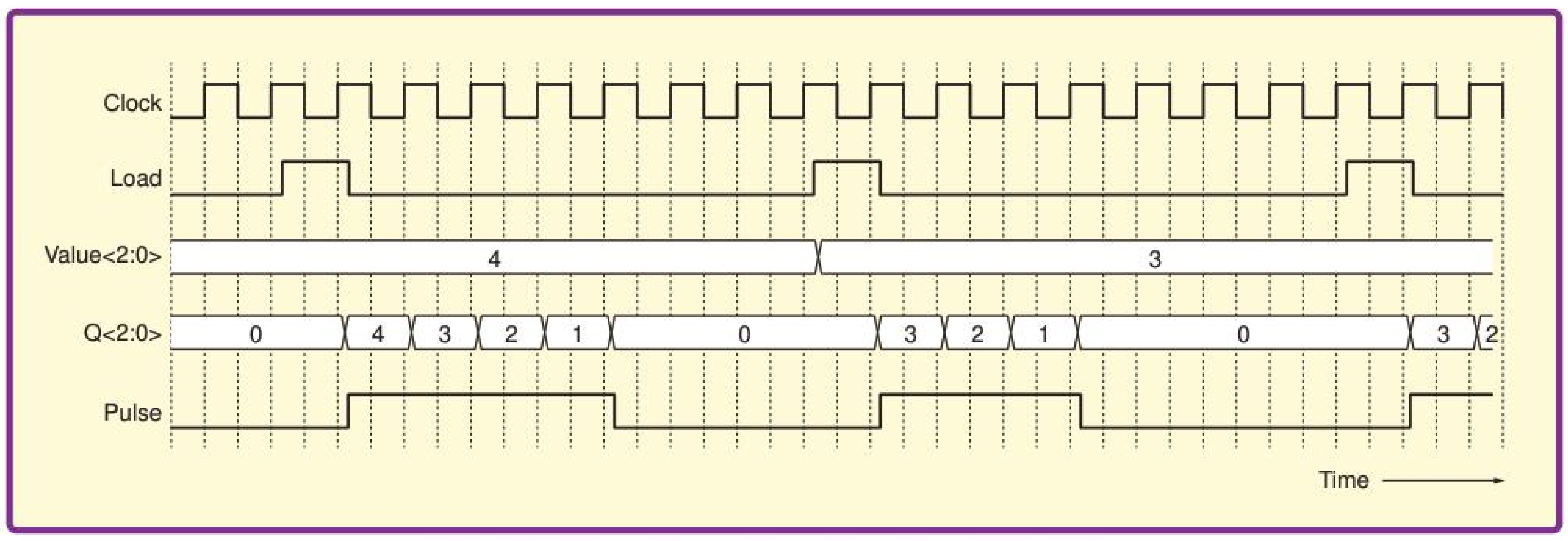


Fig.4. Waveforms for the circuit in Fig.3

transistor is low when it is conducting, keeping dissipation in the transistor low. MOSFETs are often used instead of bipolar transistors in applications such as this because they do not need a continuous gate input current when they are on. However, large currents may be required to rapidly charge/discharge a MOSFET's gate capacitance when switching. Another option, if the base current demand for a single transistor is too high, is to use a Darlington configuration, which was the subject of the February 2017 article mentioned above.

Generating PWM with a digital circuit

It is relatively straightforward to generate a PWM with a basic digital circuit. We require a time base, which will set the frequency of the PWM waveform. Typically, we need a pulse of one-clock-cycle duration at the PWM frequency to trigger each PWM pulse. This can be obtained using a binary counter configured to count continuously on the clock. Detecting when the counter is at a particular value (typically all 1s or all 0s in the count value) produces a regular one-clock-cycle-wide pulse to trigger the PWM pulse. The relationship between the clock and PWM frequencies will determine the resolution with which the PWM pulse width can be controlled.

To create the actual PWM pulses we can use the time-base signal to control loading of a presentable binary down counter, as shown in Fig.3. This counter is clocked from the same source as the free-running binary counter, which produced the time-base. A timing diagram illustrating operation is shown in Fig.4, which depicts the system changing the PWM pulse length from four to three clock cycles. The counter only has three bits in this example – sufficient for illustration, but a real PWM system would probably use many more bits.

The PWM pulse width is input to the counter as its preset value. When the time base/load pulse occurs the counter will load the pulse width value. On subsequent clock cycles it will count down. When it reaches zero this is detected by the OR gate and used to inhibit further counting. The counter will therefore stick at zero until it is loaded again. A presettable counter wired in this way is sometimes called a count-zero timer. The PWM signal is obtained by outputting a logic 1 when the count value is not zero.

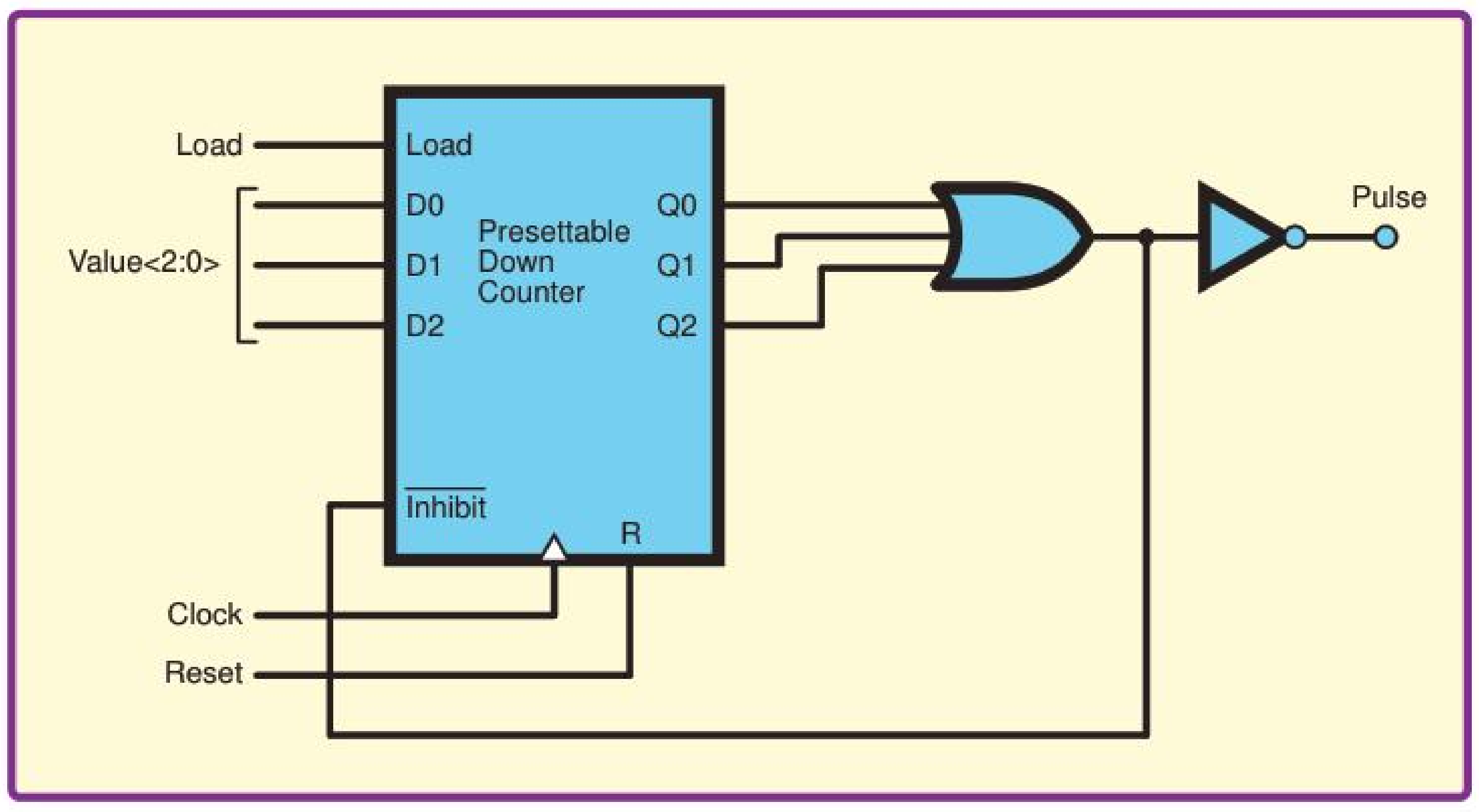


Fig.3. Presettable counter used to generate a PWM waveform

Generating PWM with a microcontroller

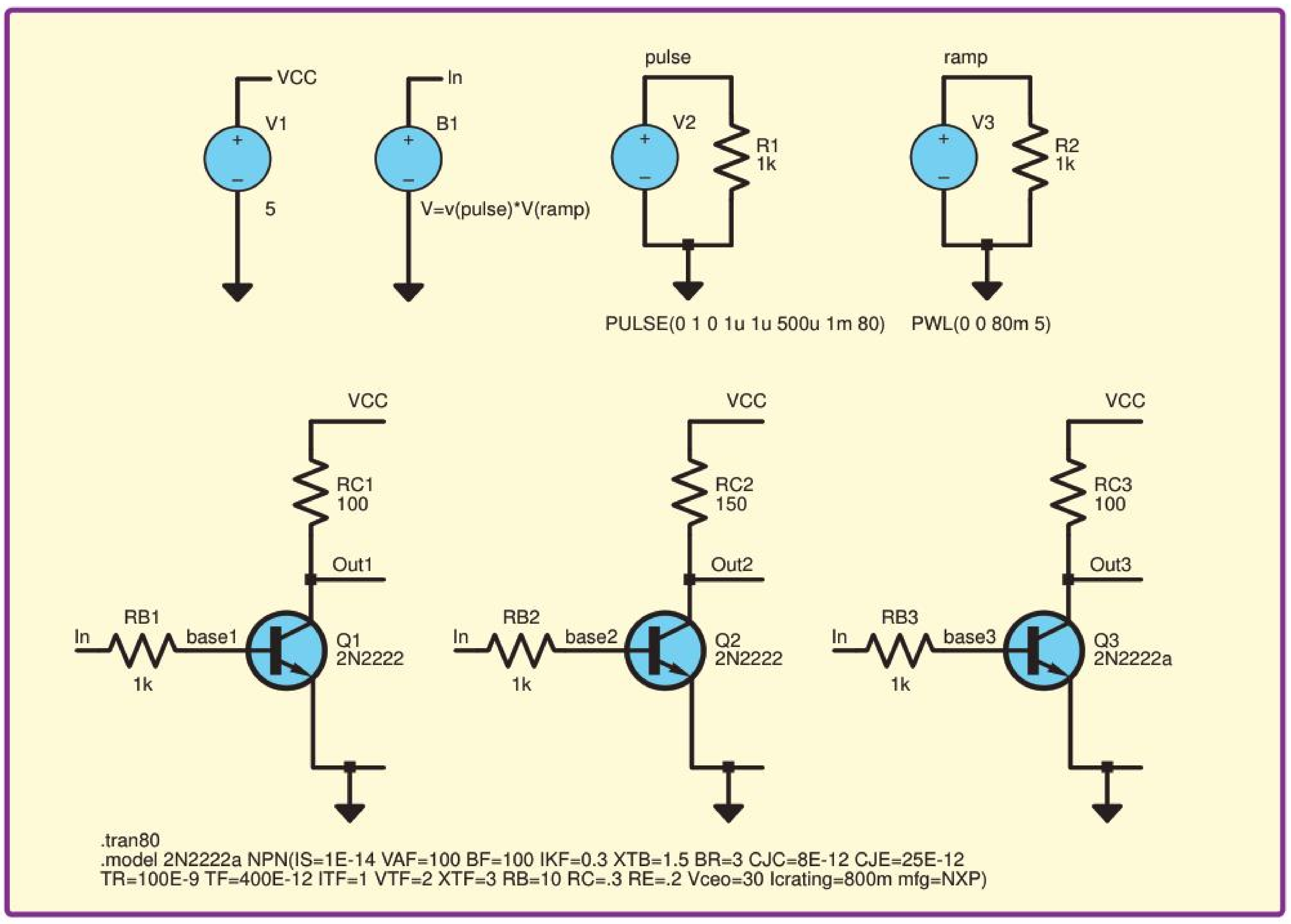
Microcontrollers often have on-chip hardware to facilitate the production of PWM signals. For example, in the popular PIC microcontrollers from Microchip the on-chip hardware used to produce PWM is typically called the Output Compare Module, which has a variety of uses, including PWM. The time period of the PWM is set by one of the chip's timers; these can be configured to produce pulses at regular time intervals by setting appropriate control registers and the relevant timer's Period Register (PR). The timer is basically a counter that counts up (at a defined rate) until the PR value is reached and is then reset to start again from zero.

In the Output Compare Module two registers are used to control the PWM pulse length (waveform duty cycle) – the output compare data register (OCR) and the secondary output compare data register (OCRS). The OCRS register holds the pulse length value set by the user. When the timer reaches its maximum value and is reset the value of the OCRS register is transferred to the OCR register. Thus the OCRS acts a buffer for the OCR – which actually controls the timing. This means that the user code can set a new value of pulse width at any time without disrupting PWM operation.

PWM wave production occurs as follows. During each timer cycle the PWM output starts at logic 1. When the timer's count value reaches the value held in the OCR register the PWM output is driven low and stays low until the start of the next timer cycle. Thus, the Output Compare Module produces a PWM pulse train with a pulse width set by the value written to the OCRS register and pulse frequency set by the PR register.

Variable voltage circuit simulation

We can investigate the properties of the circuit in Fig.1 using SPICE analogue circuit simulation. The popular free simulator LTSpice is suitable for this task. We do not have many details of noel's circuit apart from the 0 to 5V voltage range requirement, but this does not matter, we can explore the general behaviour of the circuit rather than trying to find specific numerical values.



```
.tran80
.model 2N2222a NPN(IS=1E-14 VAF=100 BF=100 IKF=0.3 XTB=1.5 BR=3 CJC=8E-12 CJE=25E-12
TR=100E-9 TF=400E-12 ITF=1 VTF=2 XTF=3 RB=10 RC=.3 RE=.2 Vceo=30 Icrating=800m mfg=NXP)
```

Fig.5. LTSpice schematic used for simulating the variable voltage PWM circuit

The circuit in Fig.1 varies the PWM voltage using a potentiometer, but for the simulation it is more convenient to use a variable voltage source directly. Doing so will mean that the properties of the potentiometer will not be included, allowing us to concentrate more directly on the switching behaviour of the transistor. On the other hand, the potentiometer should not be ignored, so we address this first (with some 'hand waving' calculations).

Ideally, the potentiometer should provide a 'strong' voltage source that is not loaded by the transistor's base current. If we assume a load of 100Ω (smaller than in Fig.1), then the load current is 50mA, and if we assume the transistor is in saturation with a forced beta in the order of 10-20 then that works fine with a 1kΩ resistor to limit base current to around 4mA from a 5V base drive. Using the rule of thumb that a potentiometer should be at least ten-times smaller than the load resistance connected to its wiper indicates a 100Ω potentiometer, which is a rather low resistance, and which may be difficult for the microcontroller to drive.

We would probably get away with a larger potentiometer resistance if we ignored the loading problem, but if its resistance is too large the base current may be limited too much. A loading-affected potentiometer may prevent us from calibrating the scale with the load voltage, but other issues with this circuit are likely to cause the same problem. If the power required by the load is much lower, all currents will be lower and this problem will be less severe.

Simulation set up

The schematic used for the LTspice simulation is shown in Fig.5. There are three copies of the transistor and load circuit (based on Fig.1) so that we can simultaneously compare three different scenarios, specifically to vary the load resistance and transistor gain. The 2N2222 is not used for any special reason – it is first on the list and is suitable to represent a generic transistor in this simulation. The Q1 circuit has a 100Ω load and a forward current gain (β_F or BF in SPICE) of 200, as set by the 2N2222 transistor model in LTspice. The Q2 circuit also has a default 2N2222 model, but the load is 150Ω. The Q3 circuit has a load of 100Ω, like Q1, but the transistor has a gain of 100.

The gain of 100 for Q3 is achieved using a custom model for that transistor, named 2N2222a. To do this on LTspice the original `.model` directive code is copied from the supplied bipolar transistors model text file, which typically installs (on Windows) at location:

```
C:\Program Files (x86)\LTC\
LTspiceIV\lib\cmp\standard.
bjt
```

This is pasted into a SPICE directive on the schematic using the `.op` button. The pasted text is edited to change the model name and BF parameter value as shown below. The text must be all on one line.

```
.model 2N2222a NPN(IS=1E-14
VAF=100 BF=100 IKF=0.3 XTB=1.5
BR=3 CJC=8E-12 CJE=25E-12
TR=100E-9 TF=400E-12 ITF=1
VTF=2 XTF=3 RB=10 RC=.3
RE=.2 Vceo=30 Icrating=800m
mfg=NXP)
```

Behavioural source

A varying voltage PWM signal, which aims to replicate the signal at the wiper of the potentiometer in Fig.1 (ignoring loading), is generated using the behavioural voltage source B1. In SPICE, behavioural voltage sources allow voltages to be defined using mathematical expressions related to other circuit voltages. In this simulation the B1 source is used to multiply together a constant amplitude 1V, 1kHz square wave with a linear ramp voltage that ramps from 0V to 5V over 80ms. The square wave and ramp voltage are produced using conventional SPICE voltage sources in pulse and piecewise linear modes respectively.

The B1 source will produce a ramping-amplitude square wave, which will represent moving the potentiometer over its full range. In the interests of a full investigation we ignore the purpose of resistor R1 in Fig.1 and allow the input voltage to cover the entire 5V range in an initial simulation. In a second simulation we will restrict the voltage range.

Results

The results of the first simulation are shown in Fig.6. This only refers to the Q1 circuit. The top trace is the input signal described above. The second trace shows the base voltage; it increases more or less linearly with the input voltage until the transistor's base-emitter junction switches on and the base then shows the near-constant voltage drop of a forward-biased PN junction.

The third trace shows the load voltage. This indicates that the circuit does allow the load voltage to vary between 0 and 5V, but this occurs over a small range of input voltages. This is to be expected because the transistor's collector current, and hence load voltage drop, is highly sensitive to small base-voltage variations.

The fourth trace shows the transistor's collector voltage. This is key to understanding how the circuit is operating. When the input voltage is very low the transistor is off, the load voltage is zero and the all of the 5V supply is dropped across the transistor (collector at 5V). When the input voltage increases to the point where the transistor just conducts it enters forward active mode. As the input voltage increases the current through the load and the voltage across it increase in proportion to the input voltage, and the collector voltage (during the 'on' pulse) decreases. Thus, we can manipulate the load voltage, but it is not normal to use a transistor in the forward active region of transistor operation for PWM load power control.

Once the load current is sufficient to result in a load voltage close to the supply voltage the transistor will enter saturation, with a small, nearly constant, collector voltage (during the 'on' pulse). This is the normal region of transistor operation for PWM load power control. Further increases in input voltage will not decrease collector voltage or increase load voltage or current, but using a larger input voltage will ensure the transistor remains saturated if the load resistance

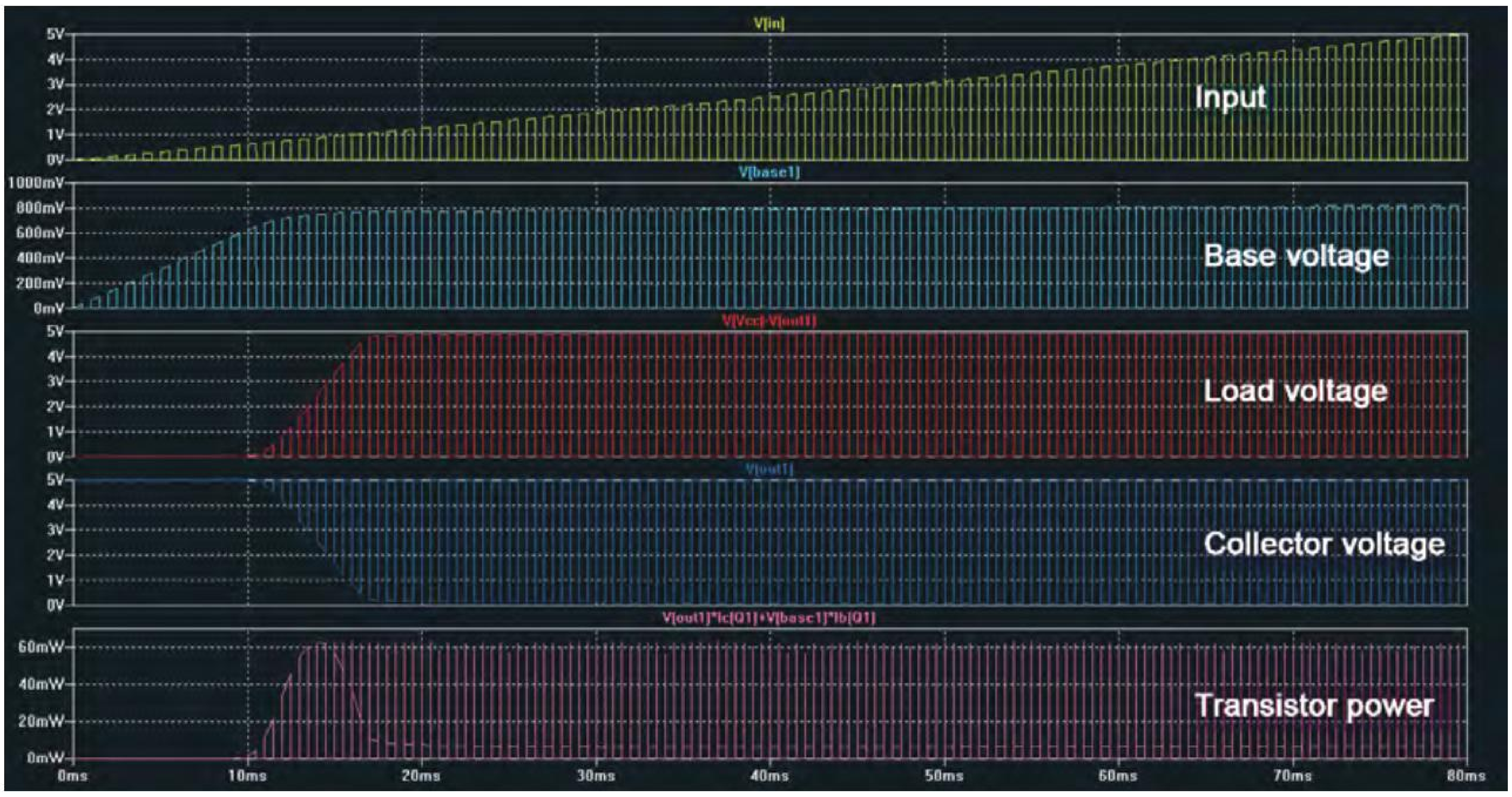


Fig.6. Simulation results for the circuit in Fig.5

varies. Base current will increase with increased input voltage.

In the region of varying load voltage – from about 10 to 17ms in the simulation – the transistor is in forward active mode and the collector current (I_C) is equal to β_F times the base current, which is in turn set by the input voltage. The collector current flows through the load, R_{C1}, giving a voltage drop across the load of $I_C R_{C1}$. This highlights one of the problems with this circuit – in this region of operation we are really controlling the load current, not the load voltage. The load voltage therefore depends on the load resistance and transistor gain, so the circuit does not provide proper control of voltage for loads with variable resistance. Again, we cannot calibrate the voltage input control.

The fifth trace in Fig.6 shows power dissipation in the transistor. This curve comprises the power dissipation when the load is on and the power spikes that occur during switching. Here we are mainly interested in the former. When the transistor is off (before about 10ms in the simulation) and when it is in saturation (after about 17ms) the transistor dissipation when the load is on is small. In the region where the transistor is in forward active mode, and has a significant collector voltage while it is on, there is much higher dissipation in the transistor. This is the region where we have 'voltage control', thus it comes at the expense of inefficient switching. This limits the circuit to being used for load powers much smaller than can be controlled using the normal saturation-based switching.

Second simulation

Results from the second simulation are shown in Fig.7. This repeats the first simulation but with the input voltage range reduced to the range that provides varying load voltage (0.62 to 1.3V was used). The first trace shows the input as before. The next three traces show the load voltage for the three transistor circuits discussed above. It can be seen that varying load resistance and transistor gain varies load voltage as discussed above (the same input voltage variation produces different load voltage variations in each case). The final trace again shows transistor power dissipation, although this time the switching spikes have been edited out to make the load-on power easier to see.

From the simulations we can see that this circuit is able to control the voltage of the PWM signal across the load, but there are several important problems. The transistor is not used in the standard way for load switching and has significantly higher power dissipation; the voltage varies with load resistances, so cannot be set for a variable load; and the load voltage depends strongly on transistor characteristics, which may vary between transistors and with temperature. The second two points and the possible loading of the potential divider (discussed earlier) mean that the voltage-setting control cannot be calibrated. The circuit could work for a rough-and-ready experiment, but a better solution would be to use a variable voltage regulator to set the PWM voltage and switch the load conventionally with the transistor fully on and off.

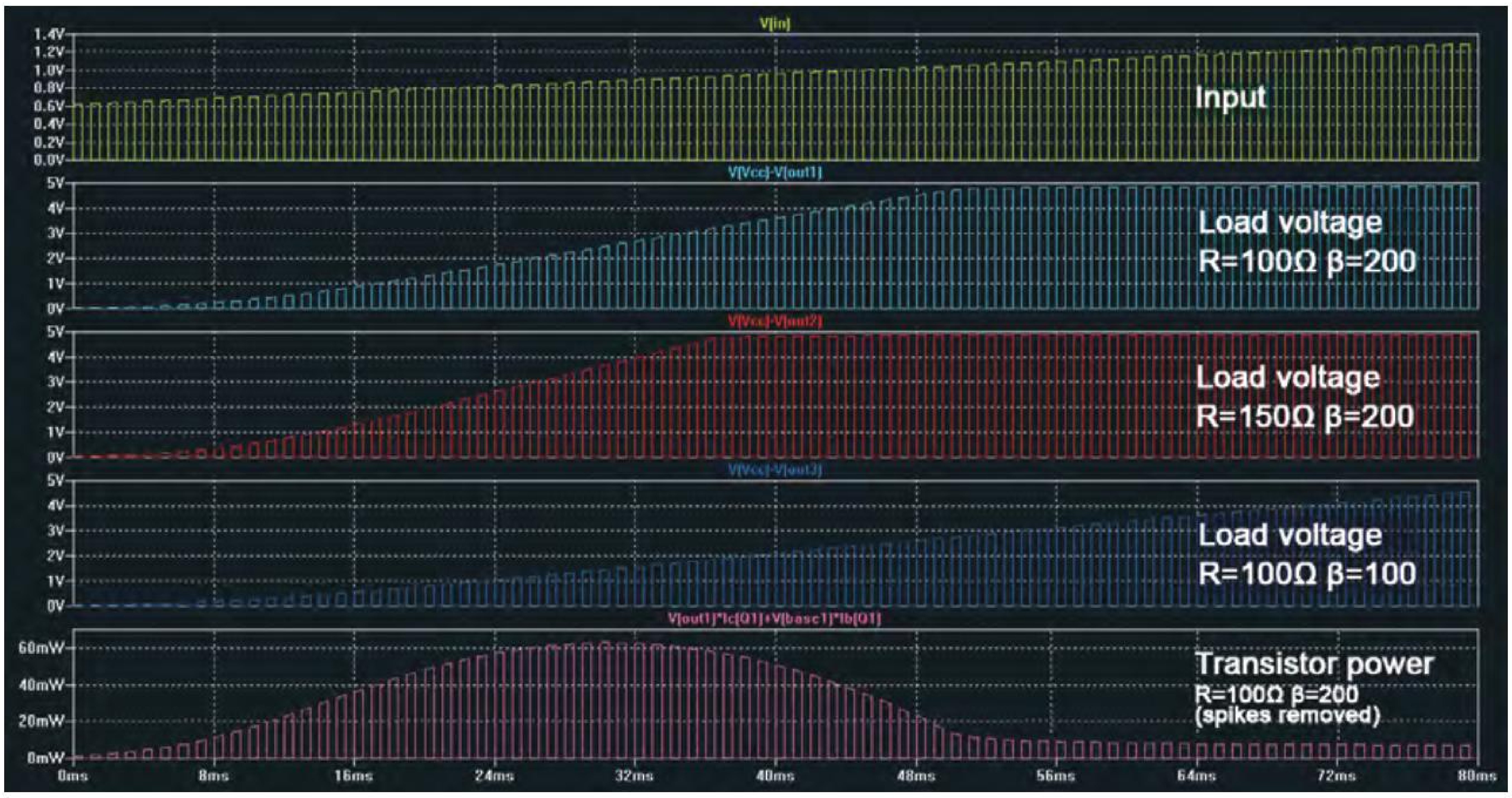


Fig.7. Simulation results for the circuit in Fig.5 with reduced input voltage range and showing the effect of varying load and transistor gain

AUDIO OUT

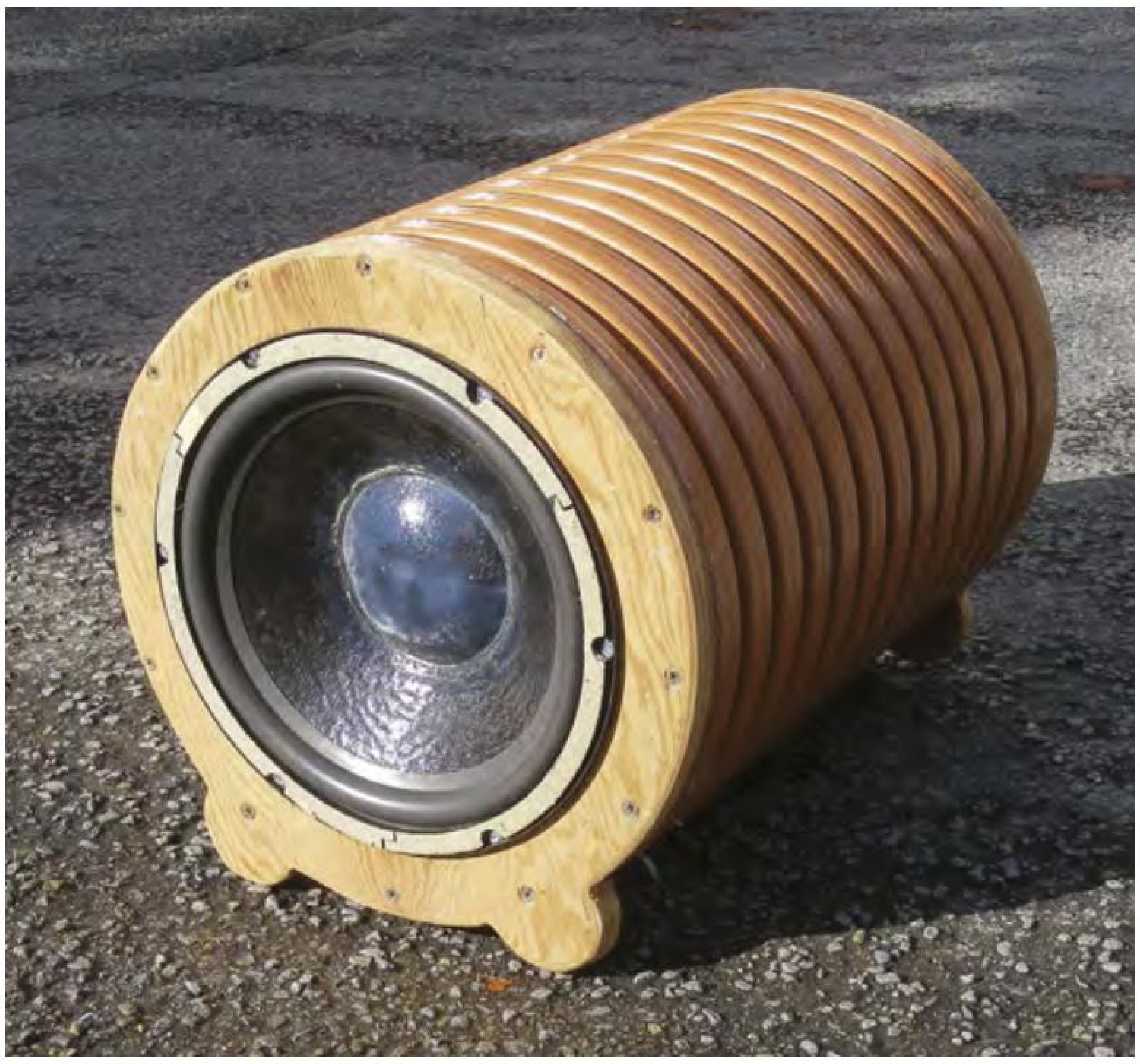
By Jake Rothman

Book reviews

I'm taking a break this month from hands-on audio to look at a couple of books. We don't do many book reviews in *EPE*, but there are some that really can't be ignored and I present here a couple of good reads with excellent practical material that I feel sure *EPE* readers will enjoy.

DIY Loudspeaker Building (2nd edition)
Julian Edgar
68 pages
CreateSpace Independent Publishing Platform
£19.75

This is the second edition of Julian Edgar's book – I confess I've not seen the first. It uses a unique practical style reminiscent of Wharfedale founder Gilbert Brigg's loudspeaker books from the 1960s. Briggs used to bolt bricks to speaker cabinet walls to control resonance problems, while Edgar glues fibre-based plant pots together to get an ideal spherical enclosure (a great idea that I have borrowed!). I couldn't get the Australian glue he used, but good old British green Gripfill from the builder's merchants worked a treat. One of his recommendations I endorse is to use commodity materials, automotive parts and to 'rat' old boot fair and charity shop speakers. Channelling Julian's innovative spirit I have used manhole mastic for panel damping, piping for enclosures and even been known to slash old mattresses to get wool wadding. Julian is right when he says building a speaker with distributor parts costs more than buying them ready made, although I'm sure my friend Malcolm Jones, KEF driver designer and the founder of Falcon Acoustics would disagree!



You don't have to be a carpenter or cabinet maker – Julian Edgar encourages innovative cabinet construction techniques. For example, drainpipes can be used to make good sub-woofers.

Julian Edgar's book is in the spirit of 1960s practical books like those of Gilbert Briggs. If you want to design studio monitors for the BBC, better buy Colloms's, but that costs three times more and is not nearly so much fun!

Julian does of course make use of modern computer techniques and that great Australian contribution to speaker design, Thiele Small parameters, for bass response optimisation. Bass response is what he regards as most important. His under-floor sub-woofer enclosures are another great idea I will use sometime. This leads onto my only doubt about his approach, in that he does not address UK design goals regarding mid-range colouration, crossover integration and bass tightness. If accurate reproduction of vocals and acoustic music is your area, and you don't like dance music and automotive audio, then I would have to refer you to much more academic books, such as *High Performance Loudspeakers* by Martin Colloms. Julian's speakers are for fun, not studio monitoring, or as Anne Dudley from the Art of Noise said recently on Radio 4, 'there is nothing like listening to music out of a big pair of 1980s wooden speakers'.

Original and practical

I love his practical tips, such as using a moistened finger to detect air leaks from enclosures. The book is liberally illustrated with clear colourful photos, essential for practical work. He also points out spec sheets often lie and that there's no substitute for actually measuring a drive units parameters. There's no need to buy expensive flared bass reflex tubes, he just uses a heat gun and presses a

DIY Loudspeaker Building - 2nd edition
Julian Edgar

Watch out! – speaker building can become addictive and lead to divorce!

PVC pipe against a hard china bowl. However, I don't want to give too much away and the book only costs £19.95 from Amazon.

As well as the upcycling movement, which Julian was in on from the beginning, there has recently been a return to the pleasures gained from artisan craft skills, such as the Maker movement. I can see this book introducing many to the delights of home-brewed speakers. But beware, in my case I now have over 40 pairs!

Learning the Art of Electronics – A Hands-on Lab Course

Thomas Hayes, Paul Horowitz
1147 pages
Cambridge University Press
£35.99

This is the replacement for the *Art of Electronics Student Manual*, which was originally designed to accompany *The Art of Electronics* (*AoE*). No longer a little ring binder notebook with beautiful hand-drawn diagrams, it is now a 1141-page 2kg behemoth. Some amusing diagrams are there; it is the first time I'd seen a circuit with emoticons describing decoupling (p.75). Hill's excellent hand drawn internal schematic of the LF411 op amp is still present (p.396) which shows you how to draw and annotate properly. No 'Euro boxes' here, just sensible clear US/Mil standard symbols. It is basically the course book for the renowned Harvard Physics department's electronics course, which is partly delivered by lecturer Tom Hayes. The book is dense because at least 30 years' experience is distilled into it.

I actually bought this book along with the accompanying *Art of Electronics* (third edition) before I was asked to review it. It cost £32.42 along with *AoE* at £50.77 from **speedyhen.com**, cheaper than Amazon. Both were genuine items, not the counterfeit copies sometimes encountered online. Do note that you do not need to use this book with the *AoE*, it stands on its own.

Start at the beginning

The book starts electronics at the beginning and is practical and component centred, rather than taking a maths-based approach – unlike most university course books. It only resorts to maths where it is essential. To paraphrase Lord Kelvin, 'if you can put a number to it you know what you are talking about'.

The *Lab Course* also takes components apart so one can see how they work. I always get my students to unwind an old Mullard polyester foil capacitor, cut up an electrolytic and prise a pot apart, but it seems like the guys at Harvard were doing this before me.

The section on reading components – which causes so many problems for beginners – was the best I've read. It brought back memories of a Racal 9835 counter I tried to fix. Confusion reigned because all the 74xxx series TTL chips were date coded 74xx.

The section on stability was illuminating, even for experienced design engineers. I always like graphs with circles saying 'trouble!' where curves intersect (p382).

Digital clarity

The digital section is great for teaching and it showed me how much I've got to learn in the area of microcontrollers. It does not rely on assumed knowledge like most books. The sections on glue logic (gates) and ADC/DAC conversion and sampling, where I have some experience, had all the essential information.

My criticisms are few; a missed off H (±2.5%) from the tolerance listing, too heavy to be a paperback and the awful digital scope screen-shots. However, I do sympathise with the authors here – why do most digital scopes produce a print file akin to an Etch-a-Sketch viewed through a tea strainer? Better results are achieved with photos of an analogue scope screen. I was pleased to see that the book rightly advises in the no-compromise section on equipping the lab and component stock, that beginners should get a second-hand analogue 'scope while they are still cheap.

More than a 'Lab Course'

Finally, as any good educational resource should, some interesting student projects are included and systems employing rotating mirrors and lasers are always a winner. The book also has a concise index, often missing from many books today. It has lots of part numbers in it, great for analogue fans like me.

It is not just a student's manual now, it is also an essential reference for university lecturers and I'll be using its material in my audio electronics courses for years to come.

Next month

In my next column, I'll return to soldering and design with a look at an excellent amplifier kit that shows you 'how to make a posh power amp for peanuts'.

HAYES
HOROWITZ
LEARNING
THE ART OF ELECTRONICS
A Hands-On Lab Course
CAMBRIDGE

Weighing in at over 2kg, my already-well-thumbed issue will take me over a year to fully digest.

Max's Cool Beans

By Max The Magnificent

The nth sense

In my previous column, I described how I am embarking on a new project to create something I call my *Bodacious Brain*. The first incarnation of this little beauty is going to be presented in a domed glass cylinder approximately 600mm tall and 250mm in diameter. (If it ends up being as awesome as I anticipate, a much larger incarnation could be in my future).

I'm planning on mounting this glass cylinder on an ornately carved wooden base, which will be loaded with sensors. At the time of writing, I haven't made a final decision as to which senses my brain will boast, except that I know I want it to respond to sound.

I also know that I don't want my brain to be limited to a single microphone – I want its auditory senses to be omnidirectional so that it can determine the direction from which a sound originates. Fig.1 shows a setup my chum Sree Harsha Angara threw together one weekend. It boasts a 60-pixel ring of tri-colored LEDs and six microphones. Sree is an applications engineer (AE) at Cypress Semiconductor, so he powered his creation with one of their PSoC (Programmable System-on-Chip) devices. When you make a sound, like clicking your fingers, the PSoC works out which microphone heard that sound first and lights the corresponding segment of LEDs.

In addition to sound, I think the *Bodacious Brain* should also respond to light in some way, such as sudden changes in ambient lighting conditions. I'm also thinking of using multiple ultrasonic sensors to detect when things are moving near the brain: approaching it, receding from it, or walking around it.

Whatever sensors we do provide, we will use them to feed stimulus into the main body (no pun intended) of the *Bodacious Brain*.

Flexing the old gray matter

And so we come to the brain itself. The idea is for this to be formed from a three-dimensional matrix of artificial neurons. Each of these simple neurons will have some sort of processing element and some number of connections to surrounding neurons. Also, each neuron will have an associated tri-colored LED to indicate its current state-of-play.

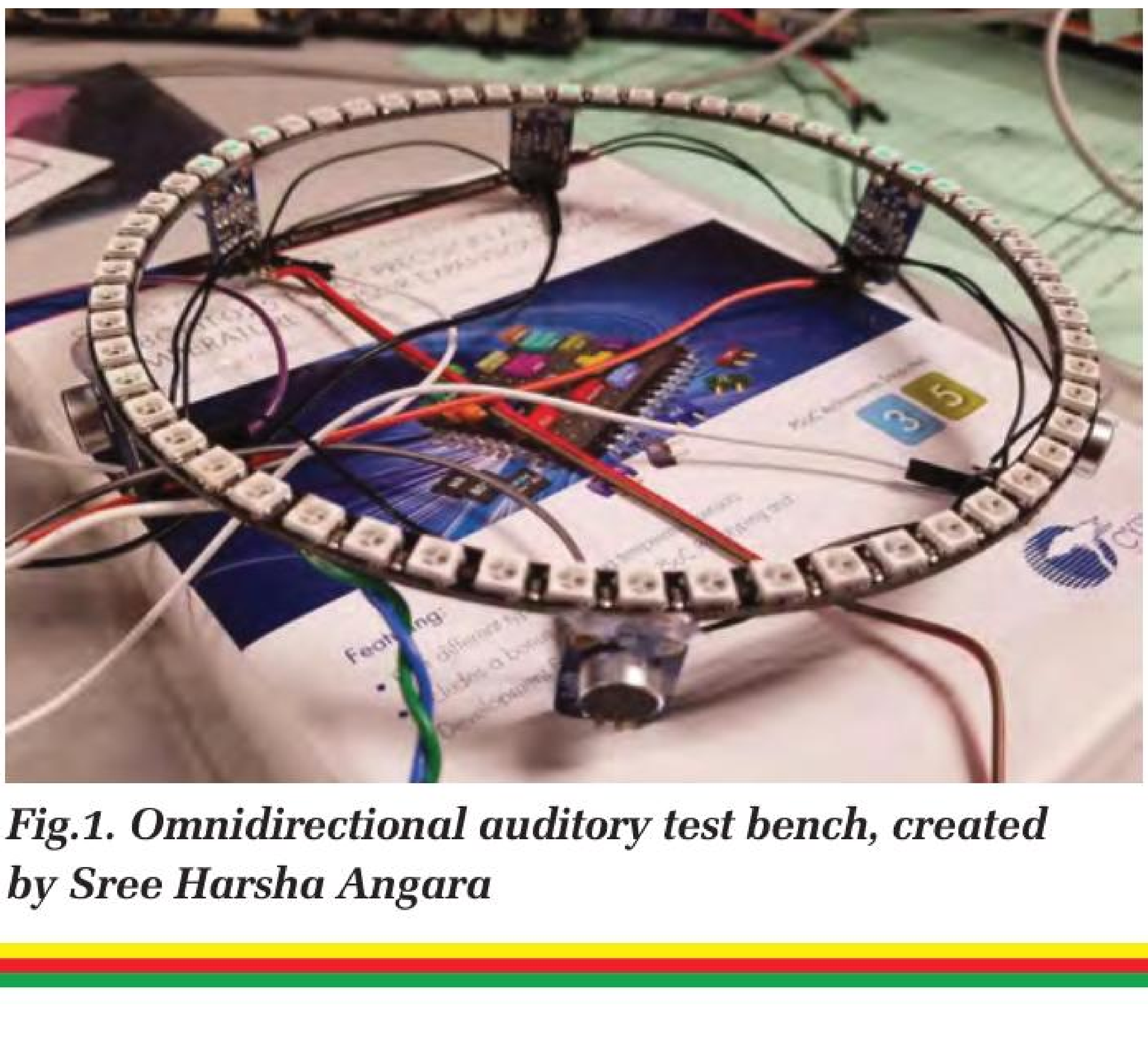


Fig.1. Omnidirectional auditory test bench, created by Sree Harsha Angara

The idea is that each neuron will act independently. It will monitor any input signals originating from surrounding neurons (or from the brain's primary senses/sensors) and – based on the stimulus it receives – it will manipulate its LED and feed output signals back into the matrix for use by other neurons.

The actual implementation details are still up in the air. Should the neural matrix be nice and neat, for example, or should it be higgledy-piggledy (random). Personally, I'm tending toward the latter option, but I'm still open to persuasion the other way.

Originally, I was toying with the idea of each neuron having knowledge of its relative X-Y-Z location in the 3D matrix. My thought was that, ideally, the neurons would determine their locations as part of a self-discovery process when the brain was initially powered up, thereby making it easier to keep on adding more-and-more neurons over time.

However, I'm now moving away from this idea. The main reason for considering it was that I was also thinking of using the brain as a sort of spectrum analyser display for music, but I already have my *Bodacious Acoustic Diagnostic Astoundingly Superior Spectromatic* (*BADASS*) display for that (see my video at: **http://bit.ly/1I5ncTc**, and June to October 2014, *EPE*). The whole thing about the *Bodacious Brain* is that it should respond to stimulus in a random manner; also, not implementing spatial awareness will make our lives much easier.

The answer's 42 – what's the question?

The big question at the moment is what we're going to use as the processing element at the center of each neuron. My initial thought was to use Arduino Nanos (Fig.2) because they are cheap (you can pick them up for $3 a piece if you look around) and I have a lot of experience with them.

One big advantage with Arduino Nanos is that their 0.1-inch pin pitch means you can use them on breadboards. I have about 25 of these little scamps here in the office, so these are what I was planning on using as the basis of my prototype, until... but let's not get ahead of ourselves.

Another big advantage is that they have 20 pins I can use as digital inputs and outputs. One point I should probably mention at this stage is that, whatever I decide to use as the processing element, once I've finished experimenting, the final implementation will use preprogrammed processors mounted on custom breakout boards. I'm visualising ~35mm circular boards with the processor mounted on one side, the tri-colored LED mounted on the other, and a ring of vias for power, ground, and input/outputs around the periphery.

An alternative processing element would be one of Cypress Semiconductor's PSoC devices. These little rascals

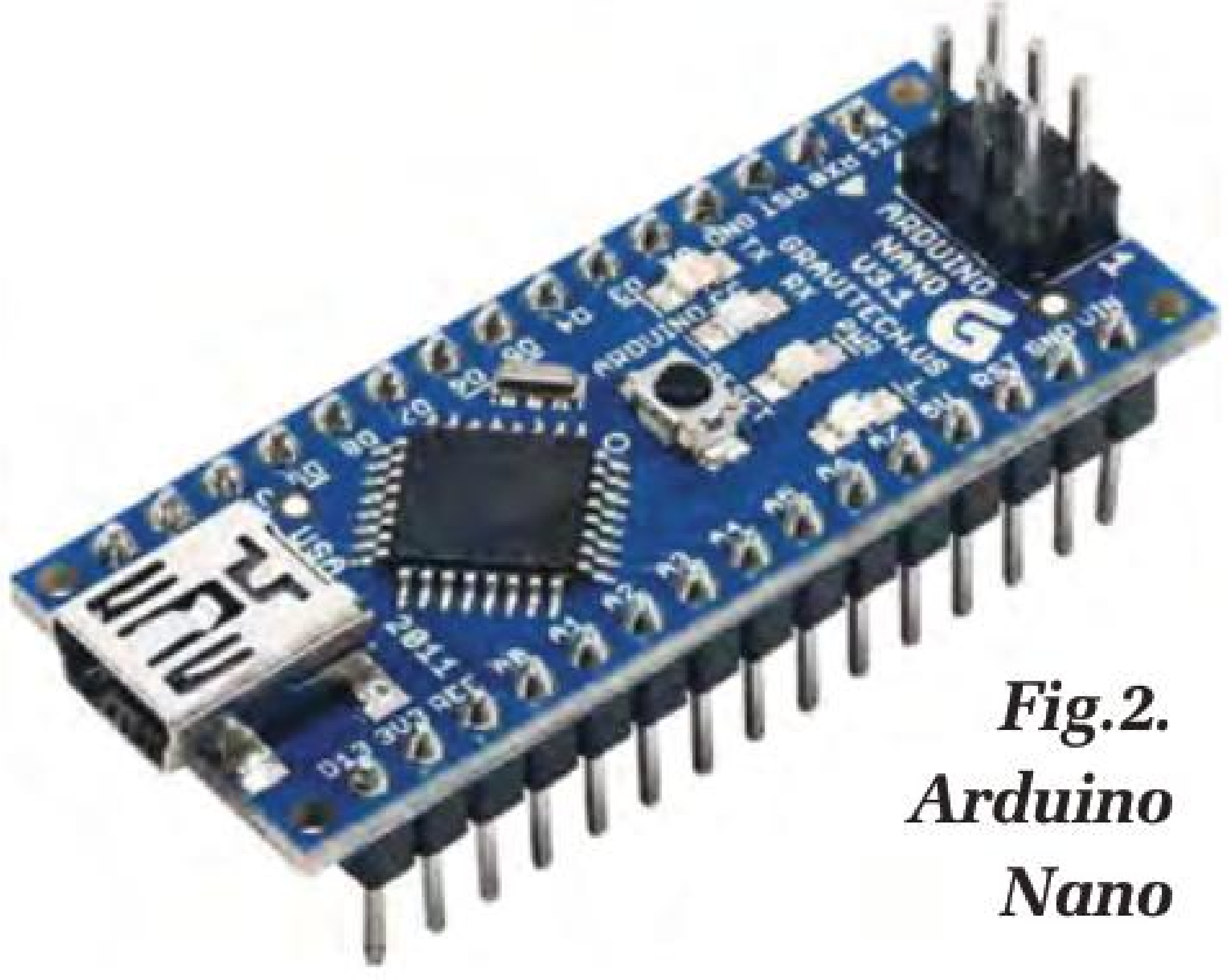


Fig.2. Arduino Nano

boast a block of programmable analogue fabric, a block of programmable digital fabric, and a processor core (an 8-bit 8051 or a 32-bit ARM Cortex), all on the same silicon chip. They also have a rather nice drag-and-drop graphical interface you can use to configure the functionality of the programmable analogue and digital blocks using pre-defined functions.

However, a surprise contender has recently leaped to the fore – the GreenPAK5 (**http://bit.ly/2k54pkd**) from **Silego.com**. These teeny-tiny (2mm × 3mm) devices are jam-packed with functional goodness, including four analogue comparators, two voltage references, seventeen digital function blocks (flip-flops, latches, look-up-tables, delays, and counters), an 8-byte RAM, and – of particular interest here – an asynchronous state machine (ASM).

The ASM boasts eight states with 24 inputs (three per state), and it's equivalent to having a simple microcontroller (MCU) running approximately 100 lines of code. Although most engineers cower at the thought of asynchronous state machines, this little scamp has been implemented in such a way as to ensure no metastability issues, no race conditions, and full determinacy, even when multiple inputs transition simultaneously.

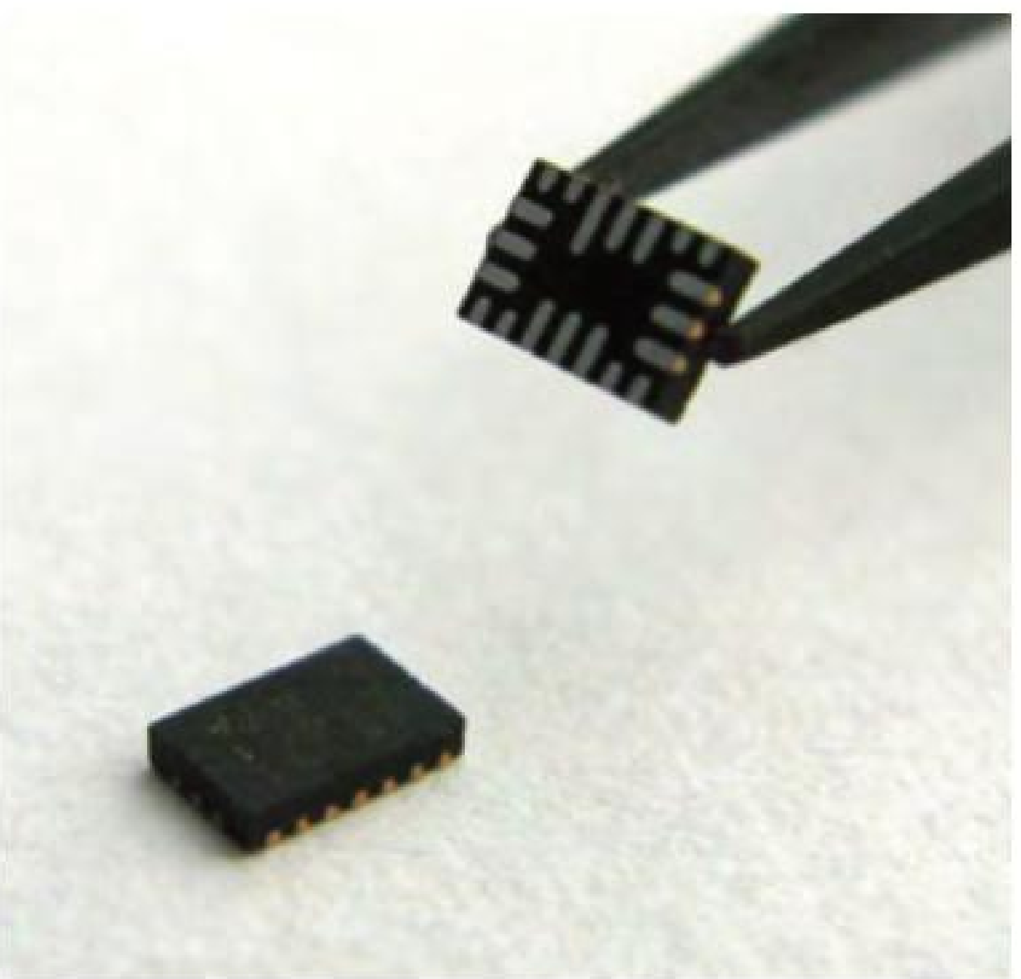


Fig.3. GreenPAK5 from Silego

Silego has a really intuitive, easy-to-use graphical design environment called GreenPAK Designer that you can download for free. Although GreenPAK devices are really intended to be purchased and used in the hundreds of thousands as part of large production runs, they are also available individually for only $1.25 on small, 20-pin breakout boards with 0.1-inch pitch headers suitable for use on breadboards. You also need a $60 development/programmer board (**http://bit.ly/2l5lNpW**), but happily I already have one sitting on my desk (what are the odds?).

On the one hand, this isn't going to give my neurons as much processing power as I was originally expecting. On the other hand, it's nice to have something you can 100% wrap your brain around and, the more I think about it, the more an ASM-based neuron seems to be the right way to go. I'm going to have to noodle on this for a while and I will report further later. In the meantime, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

GET THE LATEST COPY OF OUR TEACH-IN SERIES

ON SALE in WHSmith and other independent newsagents

FREE CD-ROM
ELECTRONICS TEACH-IN 7
£8.99
FROM THE PUBLISHERS OF EPE EVERYDAY PRACTICAL ELECTRONICS
DISCRETE LINEAR CIRCUIT DESIGN
- Understand linear circuit design
- Design simple, but elegant circuits
- Learn with 'TINA' – modern CAD software
- Five projects to build: Pre-amp, Headphone Amp, Tone Control, VU-meter, High Performance Audio Power Amp

FREE CD-ROM ALL THE CIRCUIT SOFTWARE FOR THE TEACH-IN 7 SERIES
Teach-In 7
Discrete Linear Circuit Design
PLUS...
AUDIO OUT
An analogue expert's take on specialist circuits
PRACTICALLY SPEAKING
The techniques of project building

'A complete introduction to the design of analogue electronic circuits. Ideal for everyone interested in electronics as a hobby and for those studying technology at schools and colleges. Supplied with a free Cover-Mounted CDROM containing all the circuit software for the course, plus demo CAD software for use with the Teach-In series'

GET YOUR COPY TODAY JUST CALL 01202 880299 OR VISIT OUR SECURE ONLINE SHOP AT: WWW.EPEMAG.COM

EPE IS PLEASED TO BE ABLE TO OFFER YOU THESE

ELECTRONICS CD-ROMS

From £49.00

FEATURED IN OUR TEACH-IN 2015 SERIES

TINA Design Suite V10

Analogue, Digital, Symbolic, RF, MCU and Mixed-Mode Circuit Simulation and PCB Design with TINA

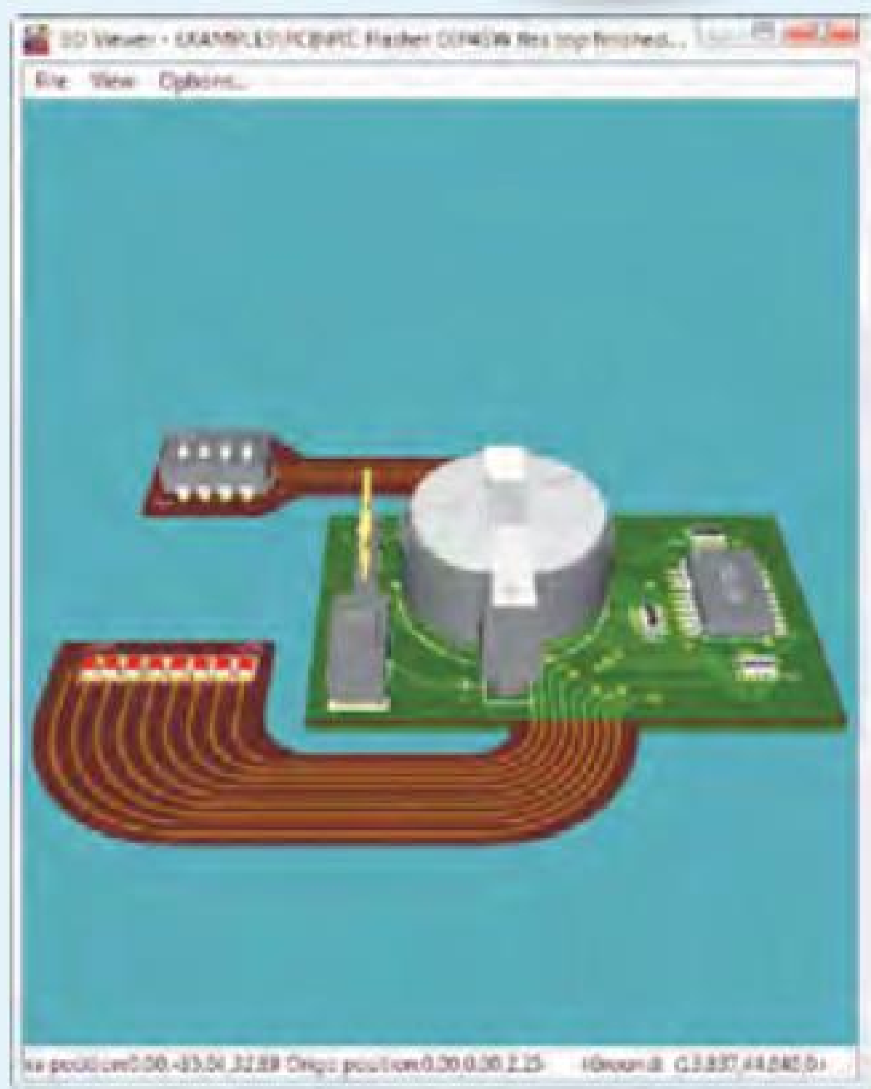
TINA Design Suite V10 is a powerful yet affordable software package for analysing, designing and real time testing analogue, digital, MCU, and mixed electronic circuits and their PCB layouts. You can also analyse RF, communication, optoelectronic circuits, test and debug microcontroller applications.

Enter and analyse any circuit up to 100 nodes (student), or 200 with the Basic (Hobbyist) version within minutes with TINA's easy-to-use schematic editor. Enhance your schematics by adding text and graphics. Choose components from the large library containing more than 10,000 manufacturer models. Analyse your circuit through more than 20 different analysis modes or with 10 high tech virtual instruments.

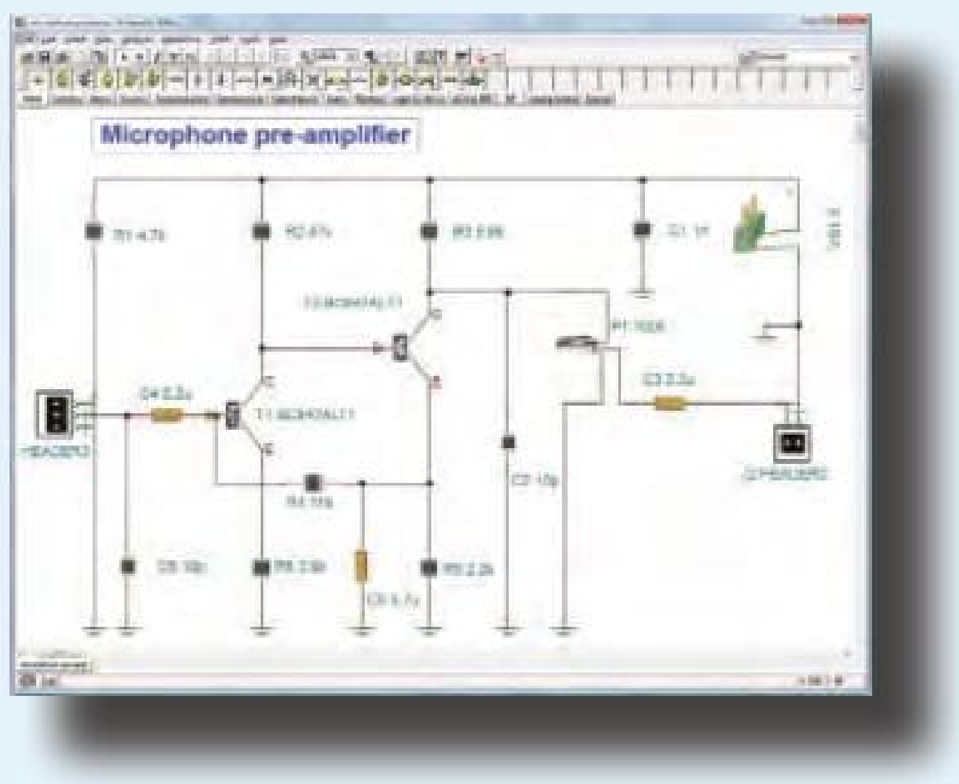
Present your results in TINA's sophisticated diagram windows, on virtual instruments, or in the live interactive mode where you can even edit your circuit during operation.

Customise presentations using TINA's advanced drawing tools to control text, fonts, axes, line width, colour and layout. You can create and print documents directly inside TINA or cut and paste your results into your favourite word procesing or DTP package.

TINA includes the following Virtual Instruments: Oscilloscope, Function Generator, Multimeter, Signal Analyser/Bode Plotter, Network Analyser, Spectrum Analyser, Logic Analyser, Digital Signal Generator, XY Recorder.



This offer gives you a CD-ROM – the software will need registering (FREE) with Designsoft (TINA), details are given within the package.



Get TINA Basic V10 (Hobbyist) for £129 or Student V10 version for £49

Prices include VAT and UK postage

+ *get a 1 year free subscription for TINACloud the breakthrough cloud version of TINA which you can run on most operating systems and computers, including PCs, Macs, thin clients iPads and other tablets – even on many smart phones, smart TVs and e-book readers.*

To order please either fill out and return the order form, or call us on 01202 880299

Alternatively you can order via our secure online shop at: www.epemag.com

ELECTRONICS TEACH-IN 2

ELECTRONICS TEACH-IN 2 CD-ROM
USING PIC MICROCONTROLLERS A PRACTICAL INTRODUCTION

This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has now been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

Also included are 29 *PIC N' Mix* articles, also republished from *EPE*. These provide a host of practical programming and interfacing information, mainly for those that have already got to grips with using PIC microcontrollers. An extra four part beginners guide to using the C programing language for PIC microcontrollers is also included.

The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

CD-ROM **Order code ETI2 CD-ROM** **£9.50**

ELECTRONICS TEACH-IN 3

ELECTRONICS TEACH-IN 3 CD-ROM

The three sections of this CD-ROM cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on circuit design problems – from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

The CD-ROM also contains the complete *Electronics Teach-In 1* book, which provides a broad-based introduction to electronics in PDF form, plus interactive quizzes to test your knowledge, TINA circuit simulation software (a limited version – plus a specially written TINA Tutorial).

The Teach-In 1 series covers everything from Electric Current through to Microprocessors and Microcontrollers and each part includes demonstration circuits to build on breadboards or to simulate on your PC.

CD-ROM **Order code ETI3 CD-ROM** **£8.50**

ELECTRONICS TEACH-IN 4

ELECTRONICS TEACH-IN 4 CD-ROM

A Broad-Based Introduction to Electronics.
The Teach-In 4 CD-ROM covers three of the most important electronics units that are currently studied in many schools and colleges. These include, Edexcel BTEC level 2 awards and the electronics units of the new Diploma in Engineering, Level 2.

The CD-ROM also contains the full Modern Electronics Manual, worth £29.95. The Manual contains over 800 pages of electronics theory, projects, data, assembly instructions and web links.

A package of exceptional value that will appeal to all those interested in learning about electronics or brushing up on their theory, be they hobbyists, students or professionals.

CD-ROM **Order code ETI4 CD-ROM** **£8.99**

ELECTRONICS TEACH-IN 4
A BROAD-BASED INTRODUCTION TO ELECTRONICS
THE MODERN ELECTRONICS MANUAL
BASE MANUAL
ELECTRONICS TEACH-IN 3
CIRCUIT SURGERY
PRACTICALLY SPEAKING
INGENUITY UNLIMITED

NEW ELECTRONICS TEACH-IN BUNDLE – SPECIAL BUNDLE PRICE £14 FOR PARTS 1, 2, 3 & 4

CD-ROMs **Order code ETIB2** Bundle Price **£18.95**

PICmicro TUTORIALS AND PROGRAMMING

HARDWARE

PICmicro Multiprogrammer Board and Development Board

Suitable for use with the three software packages listed below

This flexible PICmicro microcontroller programmer board and combination board allows students and professional engineers to learn how to program PICmicro microcontrollers as well as program a range of 8, 18, 28 and 40 pin devices from the 12, 16 and 18 series PICmicro ranges. For those who want to learn, choose one or all of the packages below to use with the hardware.

- Makes it easier to develop PICmicro projects
- Supports low cost Flash-programmable PICmicro devices
- Fully featured integrated displays – 16 individual LEDs, quad 7-segment display and alphanumeric LCD display
- Supports PICmicro microcontrollers with A/D converters
- Fully protected expansion bus for project work
- USB programmable
- Compatible with the E-blocks range of accessories

£118 including VAT and postage

SOFTWARE

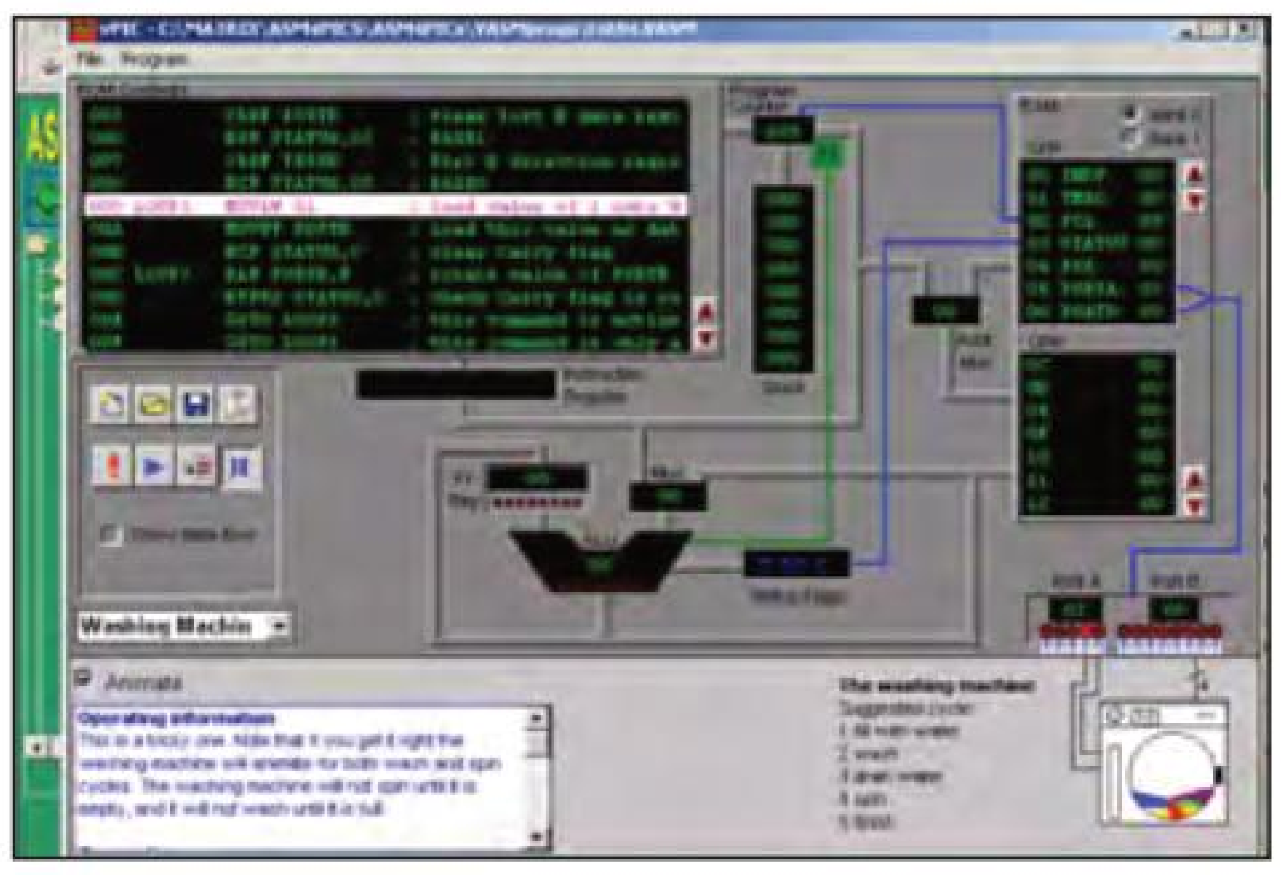
ASSEMBLY FOR PICmicro V6

(Formerly PICtutor)

Assembly for PICmicro microcontrollers V3.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84, 16F88 and 16F877a PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes.

The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

• Comprehensive instruction through 45 tutorial sections • Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator • Tests, exercises and projects covering a wide range of PICmicro MCU applications • Includes MPLAB assembler • Visual representation of a PICmicro showing architecture and functions • Expert system for code entry helps first time users • Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.) • Imports MPASM files.

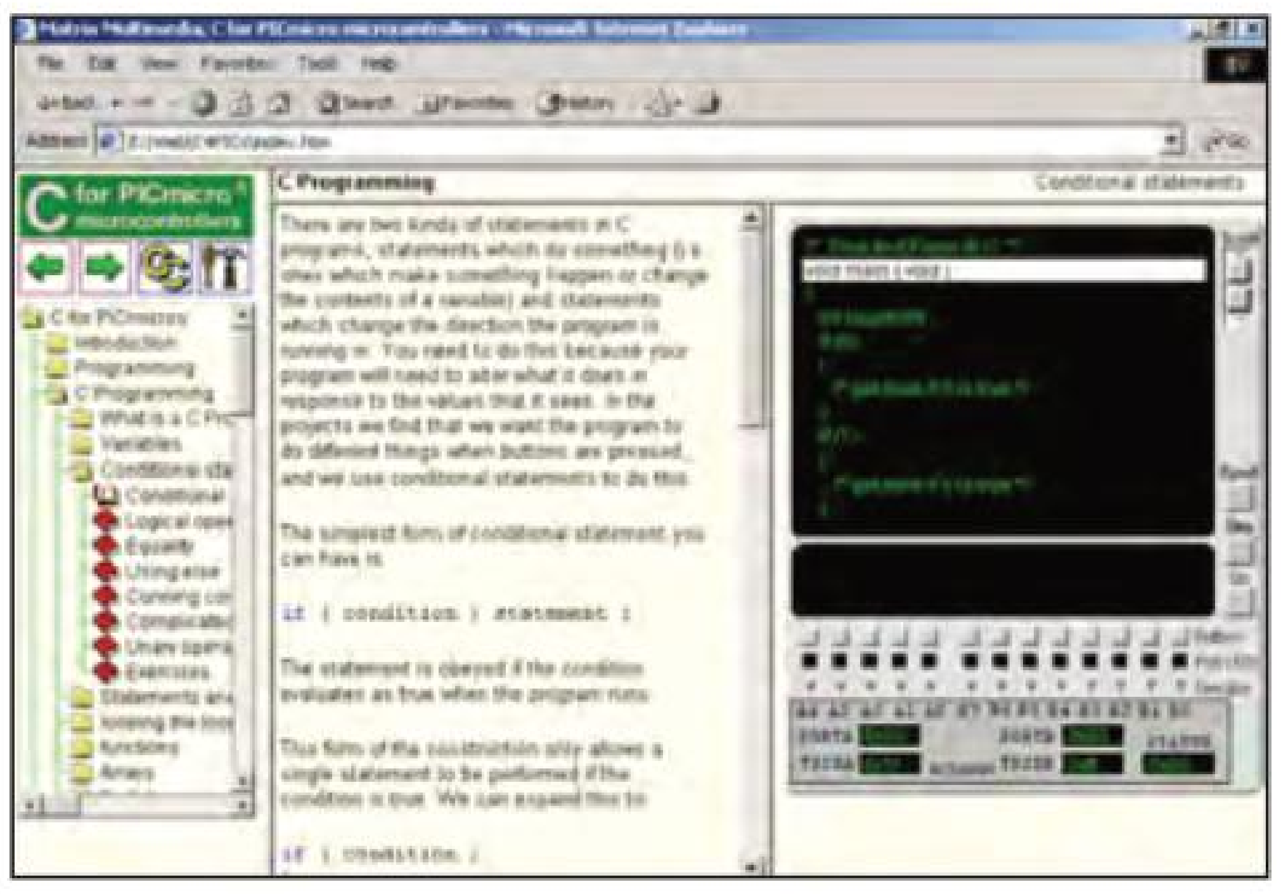


‘C’ FOR 16 Series PICmicro Version 5

The C for PICmicro microcontrollers CD-ROM is designed for students and professionals who need to learn how to program embedded microcontrollers in C. The CD-ROM contains a course as well as all the software tools needed to create Hex code for a wide range of PICmicro devices – including a full C compiler for a wide range of PICmicro devices.

Although the course focuses on the use of the PICmicro microcontrollers, this CD-ROM will provide a good grounding in C programming for any microcontroller.

• Complete course in C as well as C programming for PICmicro microcontrollers • Highly interactive course • Virtual C PICmicro improves understanding • Includes a C compiler for a wide range of PICmicro devices • Includes full Integrated Development Environment • Includes MPLAB software • Compatible with most PICmicro programmers • Includes a compiler for all the PICmicro devices.



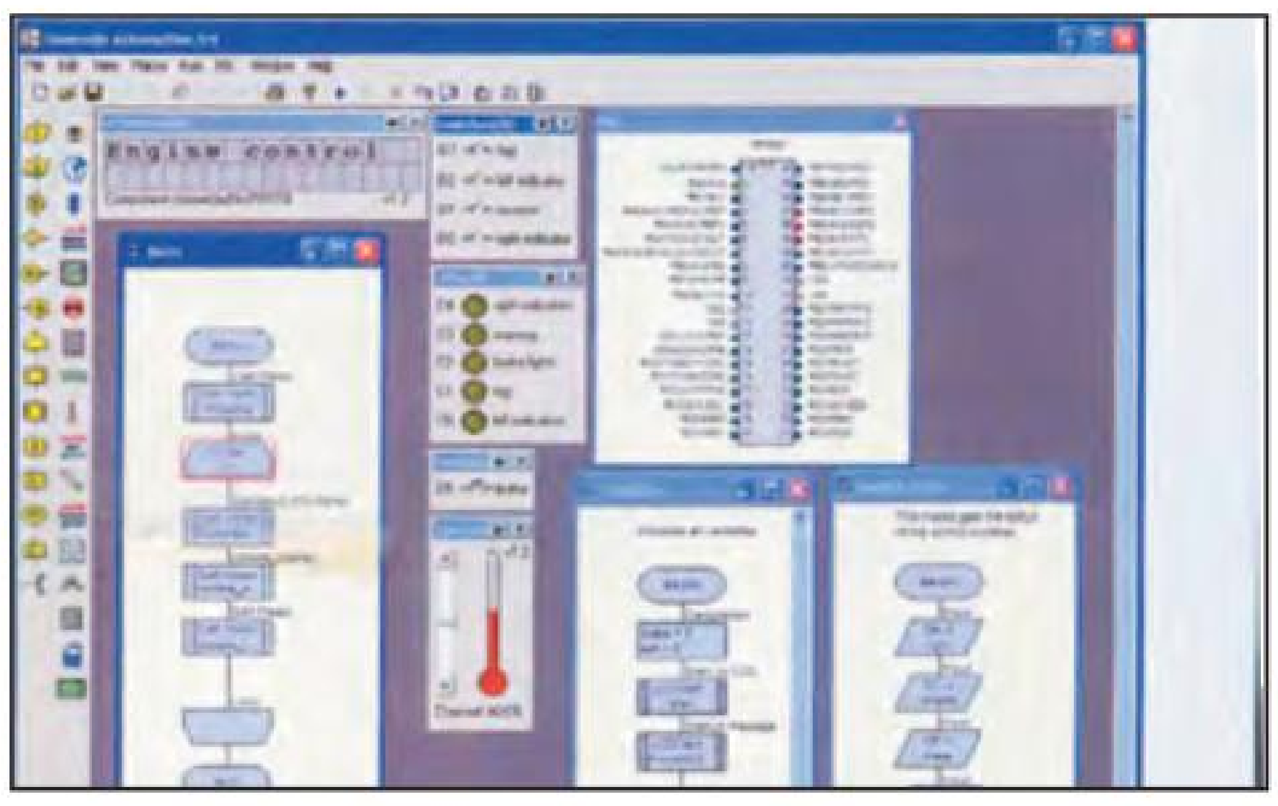
This software will run on Windows XP or later operating systems

FLOWCODE FOR PICmicro V7

Flowcode is a very high level language programming system based on flowcharts. Flowcode allows you to design and simulate complex systems in a matter of minutes. A powerful language that uses macros to facilitate the control of devices like 7-segment displays, motor controllers and LCDs. The use of macros allows you to control these devices without getting bogged down in understanding the programming. When used in conjunction with the development board this provides a seamless solution that allows you to program chips in minutes.

- Requires no programming experience
- Allows complex PICmicro applications to be designed quickly
- Uses international standard flow chart symbols
- Full on-screen simulation allows debugging and speeds up the development process.
- Facilitates learning via a full suite of demonstration tutorials
- Produces code for a wide range of devices
- 16-bit arithmetic strings and string manipulation
- Pulse width modulation
- I2C.

Please note: Due to popular demand, Flowcode is now available as a download. Please include your email address and a username (of your choice) on your order. A unique download code will then be emailed to you.



PRICES

Prices for each of the CD-ROMs above are:

(Order form on next page)

(UK and EU customers add VAT to ‘plus VAT’ prices)

Single License . . . . £99 plus VAT

Site Licence . . . . £499 plus VAT

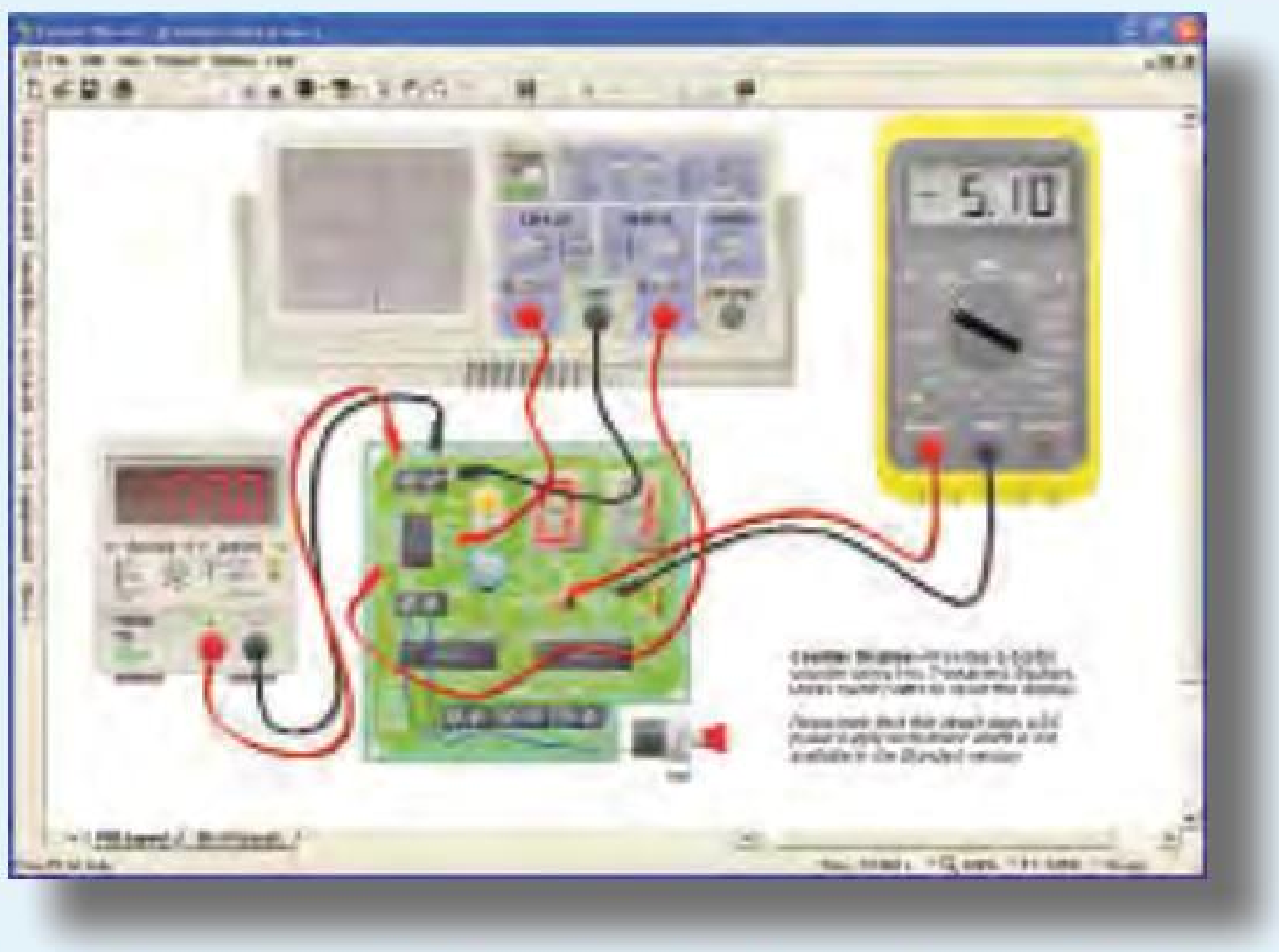
Flowcode . . . . Contact us for pricing
(choose PIC-8b, PIC-16b, PIC-32b, AVR/Arduino,ARM)

CIRCUIT WIZARD

Circuit Wizard is a revolutionary software system that combines circuit design, PCB design, simulation and CAD/CAM manufacture in one complete package.
Two versions are available, Standard or Professional.

By integrating the entire design process, Circuit Wizard provides you with all the tools necessary to produce an electronics project from start to finish – even including on-screen testing of the PCB prior to construction!

*Circuit diagram design with component library (500 components Standard, 1500 components Professional) * Virtual instruments (4 Standard, 7 professional) * On-screen animation * Interactive circuit diagram simulation * True analogue/digital simulation *Simulation of component destruction *PCB Layout *Interactive PCB layout simulation * Automatic PCB routing * Gerber export * Multi-level zoom (25% to 1000%) * Multiple undo and redo * Copy and paste to other software * Multiple document support*



This software can be used with the *Jump Start* and *Teach-In 2011* series (and the *Teach-In 4* book).

Standard **£61.25** inc. VAT. Professional **£75** plus VAT.

GCSE ELECTRONICS

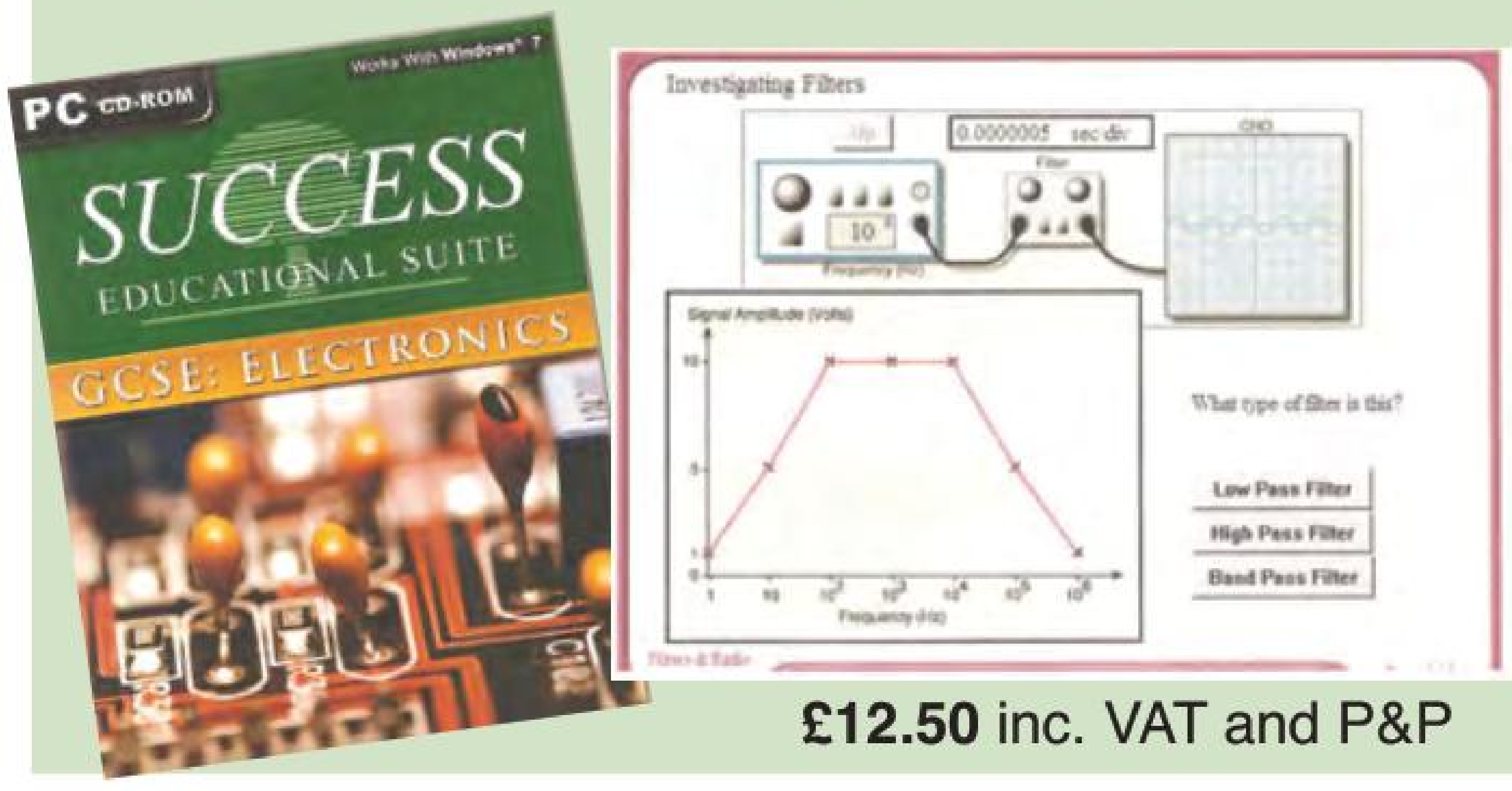
Suitable for any student who is serious about studying and who wants to achieve the best grade possible. Each program's clear, patient and structured delivery will aid understanding of electronics and assist in developing a confident approach to answering GCSE questions. The CD-ROM will be invaluable to anyone studying electronics, not just GCSE students.

**** Contains comprehensive teaching material to cover the National Curriculum syllabus * Regular exercises reinforce the teaching points * Retains student interest with high quality animation and graphics * Stimulates learning through interactive exercises * Provides sample examination ques-tions with model solutions * Authored by practising teachers * Covers all UK examination board syllabuses * Caters for all levels of ability * Useful for self-tuition and revision***

SUBJECTS COVERED

Electric Circuits – Logic Gates – Capacitors & Inductors – Relays – Transistors – Electric Transducers – Operational Amplifiers – Radio Circuits – Test Instruments

Over 100 different sections under the above headings



£12.50 inc. VAT and P&P

Please send me: **CD-ROM ORDER FORM**

☐ **Assembly for PICmicro V5**
☐ **'C' for 16 Series PICmicro V5**

Version required:
☐ **Single License**
☐ **Site licence**

Note: The software on each version is the same, only the licence for use varies.

☐ **PICmicro Multiprogrammer Board and Development Board (hardware)**

☐ **Circuit Wizard – Standard**
☐ **Circuit Wizard – Professional**
☐ **GCSE Electronics**

☐ **TINA Design Suite V10 Basic (Hobbyist)**
☐ **TINA Design Suite V10 (Student)**

☐ **Teach-In 2**
☐ **Teach-In 3**
☐ **Teach-In 4**
☐ **Teach-In Bundle**

Full name: . . . .

Address: . . . .

. . . . Post code: . . . . Tel. No: . . . .

Signature: . . . .

☐ I enclose cheque/PO in £ sterling payable to WIMBORNE PUBLISHING LTD for £ . . . .
☐ Please charge my Visa/Mastercard: £ . . . .

Valid From: . . . . Card expiry date: . . . .

Card No: . . . .

Card Security Code . . . .
(The last 3 digits on or just under the signature strip)

Minimum system requirements for these CD-ROMs: Pentium PC, CD-ROM drive, 32MB RAM, 10MB hard disk space. Windows 2000/ME/XP, mouse, sound card, web browser.

ORDERING

ALL PRICES INCLUDE UK POSTAGE

Standard/Student/Basic (Hobbyist) Version price includes postage to most countries in the world
EU residents outside the UK add £5 for airmail postage per order

Single License and Site License Versions – overseas readers add £5 to the basic price of each order for airmail postage (**do not add VAT** unless you live in an EU (European Union) country, then add VAT at 20% or provide your official VAT registration number).

Send your order to:
Direct Book Service
Wimborne Publishing Ltd
113 Lynwood Drive, Merley,
Wimborne, Dorset BH21 1UU

To order by phone ring

01202 880299. Fax: 01202 843233
Goods are normally sent within seven days

E-mail: orders@wimborne.co.uk

Online shop:

www.epemag.com

PEAK® electronic design ltd

2 Year Warranty as standard

UK designed and manufactured

Atlas DCA - Semiconductor Analyser model DCA55

Now with backlit display and AAA battery!

atlas DCA
model DCA55
PEAK® electronic design ltd
AAA Battery Edition
Base-Emitter V
VBE=1.039V
semiconductor component analyser
automatic lead identification
on - test
scroll - off
warning: avoid charge/voltages
103 x 70 x 20mm

- Connect any way round.
- Automatically identify component type.
- Automatically identify pinouts.
- Supports Transistors, MOSFETs, Diodes, LEDs and more.
- Measure transistor gain (h_{FE}).
- Measure V_{BE} (now 1mV resolution!)
- Measure leakage current.
- Measure MOSFET thresholds.
- Measure LED voltages.

Designed in the UK and made in the UK.

Just a few example screen shots:

```
PNP Germanium
Transistor     ↓
RED GREEN BLUE
Emit Coll Base ↓
Current gain
hFE=67         ↓
Test current
IC=2.50mA      ↓
Base-Emitter V
VBE=0.293V     ↓
Test current
IB=4.981mA     ↓
Leakage current
IC=0.027mA     ↓
```

```
NPN Silicon
Transistor     ↓
RED GREEN BLUE
Base Emit Coll ↓
Current gain
hFE=117        ↓
Test current
IC=2.50mA      ↓
Base-Emitter V
VBE=0.711V     ↓
Test current
IB=4.583mA     ↓
Leakage current
IC=0.000mA     ↓
```

```
PNP Darlington
Transistor     ↓
RED GREEN BLUE
Emit Base Coll ↓
Diode protection
between C-E    ↓
Current gain
hFE=9124       ↓
Test current
IC=2.50mA      ↓
Base-Emitter V
VBE=1.321V     ↓
Test current
IB=3.720mA     ↓
Leakage current
IC=0.000mA     ↓
```

```
Enhancement mode
N-Ch MOSFET    ↓
RED GREEN BLUE
Gate Drn  Srce ↓
Gate Threshold
VGS=3.47V      ↓
Test current
ID=2.50mA      ↓
```

```
Diode or diode
junction(s)    ↓
RED GREEN BLUE
Anod Cath      ↓
Forward voltage
VF=0.694V      ↓
Test current
IF=4.663mA     ↓
```

```
Three terminal
bicolour LED   ↓
Pinout for D1
               ↓
RED GREEN BLUE
     Anod Cath ↓
Forward voltage
D1 VF=1.983V   ↓
Test current
D1 IF=3.223mA  ↓
Pinout for D2
               ↓
RED GREEN BLUE
Anod      Cath ↓
Forward voltage
D2 VF=1.927V   ↓
Test current
D2 IF=3.281V   ↓
```

Universal test clips for large and small components

Available direct from us and from our distributors:

RS maplin Rapid electronics Farnell

Peak Direct Price:

£48.00

(£40.00+VAT)

Peak's insured UK delivery £3.00 inc. VAT

It's only possible to show summary specifications here. Please ask if you'd like detailed data. Further information is also available on our website. Product price refunded if you're not happy.

E&OE

Tel. 01298 70012
www.peakelec.co.uk
sales@peakelec.co.uk

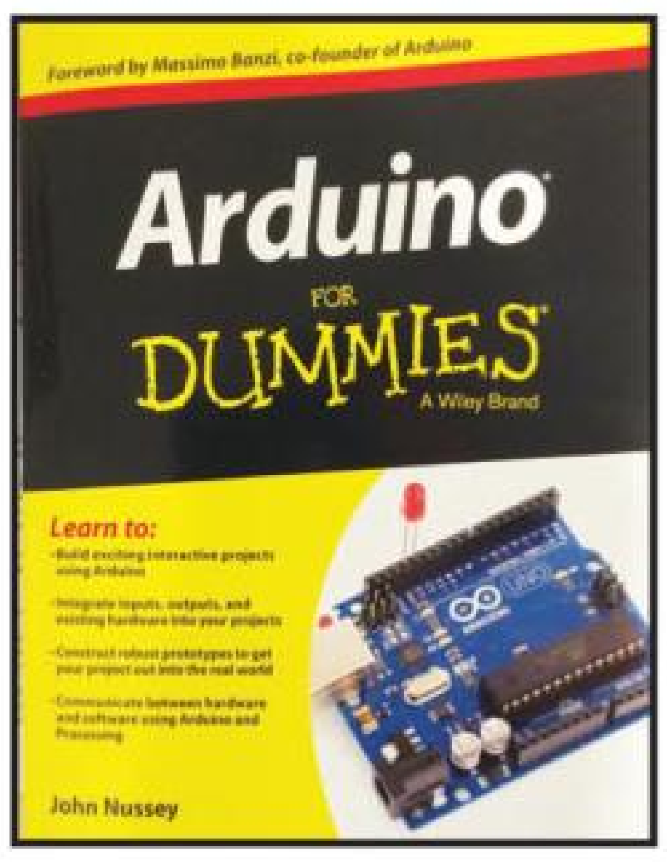
Atlas House, 2 Kiln Lane
Harpur Hill Business Park
Buxton, Derbyshire
SK17 9JL, UK

Follow us on twitter for tips, tricks and news.
@peakatlas

DIRECT BOOK SERVICE

Teach-In 2016

Exploring the Arduino

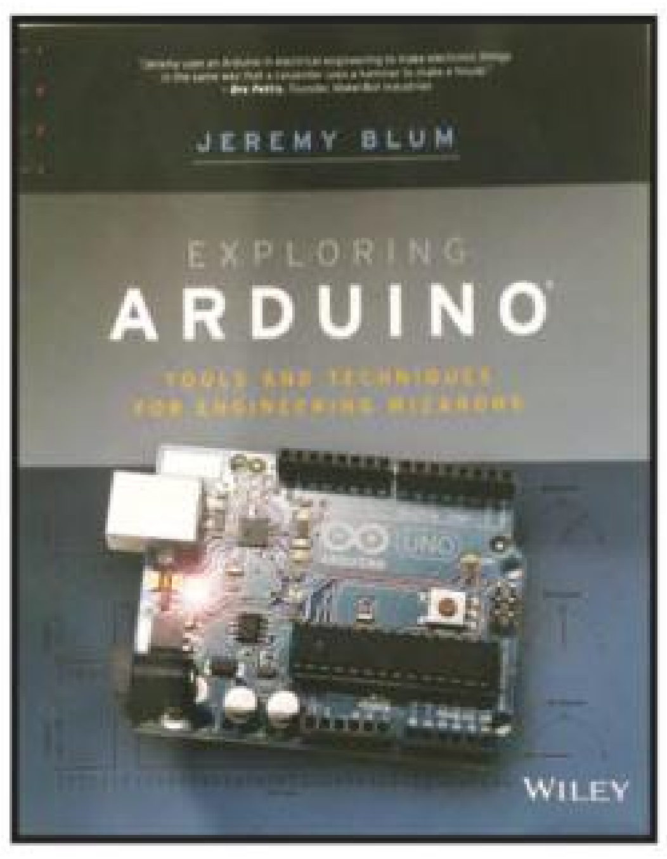


ARDUINO FOR DUMMIES
John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

- Learn by doing – start building circuits and programming your Arduino with a few easy examples – right away!
- Easy does it – work through Arduino sketches line by line, and learn how they work and how to write your own.
- Solder on! – don't know a soldering iron from a curling iron? No problem! You'll learn the basics and be prototyping in no time.
- Kitted out – discover new and interesting hardware to turn your Arduino into anything from a mobile phone to a Geiger counter.
- Become an Arduino savant – find out about functions, arrays, libraries, shields and other tools that let you take your Arduino project to the next level
- Get social – teach your Arduino to communicate with software running on a computer to link the physical world with the virtual world

438 Pages **Order code ARDDUM01** **£19.99**



EXPLORING ARDUINO
Jeremy Blum

Arduino can take you anywhere. This book is the roadmap.

Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

• Explore the features of several commonly used Arduino boards • Use the Arduino to control very simple tasks or complex electronics • Learn principles of system design, programming and electrical engineering • Discover code snippet, best practices and system schematics you can apply to your original projects • Master skills you can use for engineering endeavours in other fields and with different platforms

357 Pages **Order code EXPARD01** **£26.99**

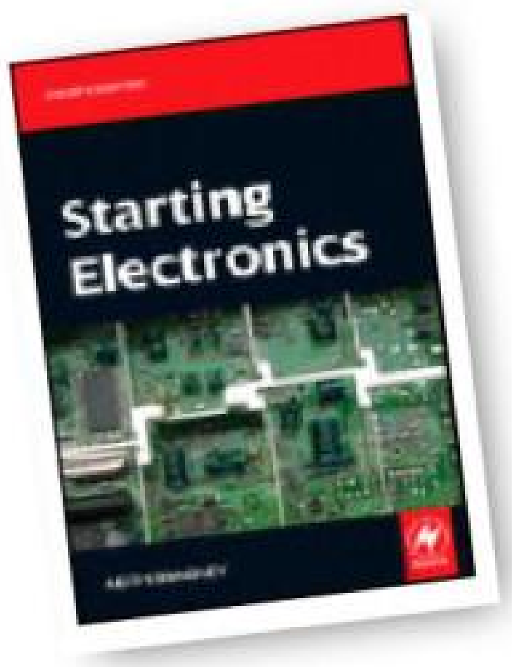
The books listed have been selected by *Everyday Practical Electronics* editorial staff as being of special interest to everyone involved in electronics and computing. They are supplied by mail order direct to your door. Full ordering details are given on the last page.

FOR A FULL DESCRIPTION OF THESE BOOKS AND CD-ROMS SEE THE SHOP ON OUR WEBSITE
www.epemag.com

All prices include UK postage

THEORY AND REFERENCE

PRACTICAL ELECTRONICS HANDBOOK – 6th Edition. Ian Sinclair
440 pages **Order code NE21** **£33.99**



STARTING ELECTRONICS – 4th Edition
Keith Brindley
296 pages **Order code NE100** **£18.99**

ELECTRONIC CIRCUITS – FUNDAMENTALS & APPLICATIONS – Third Edition Mike Tooley
400 pages **Order code TF43** **£25.99**

FUNDAMENTAL ELECTRICAL AND ELECTRONIC PRINCIPLES – Third Edition C.R. Robertson
368 pages **Order code TF47** **£21.99**

A BEGINNER'S GUIDE TO TTL DIGITAL ICs
R.A. Penfold
142 pages **OUT OF PRINT BP332** **£5.45**

UNDERSTANDING ELECTRONIC CONTROL SYSTEMS
Owen Bishop
228 pages **Order code NE35** **£36.99**

PROJECT CONSTRUCTION

IC 555 PROJECTS
E. A. Parr
167 pages **Order code BP44** **£5.49**

ELECTRONIC PROJECT BUILDING FOR BEGINNERS R. A. Penfold
135 pages **Order code BP392** **£5.99**

PRACTICAL FIBRE-OPTIC PROJECTS
R. A. Penfold
132 pages **Order code BP374** **£5.45**

MICROPROCESSORS

INTERFACING PIC MICROCONTROLLERS – SECOND EDITION Martin Bates
298 pages **Order code NE48** **£34.99**

PROGRAMMING 16-BIT PIC MICROCONTROLLERS IN C
– LEARNING TO FLY THE PIC24 Lucio Di Jasio
(Application Segments Manager, Microchip, USA)
496 pages +CD-ROM **Order code NE45** **£38.00**

INTRODUCTION TO MICROPROCESSORS AND MICROCONTROLLERS – SECOND EDITION
John Crisp
222 pages **Order code NE31** **£29.99**

THE PIC MICROCONTROLLER
YOUR PERSONAL INTRODUCTORY COURSE – THIRD EDITION. John Morton
270 pages **Order code NE36** **£25.00**

PIC IN PRACTICE (2nd Edition)
David W. Smith
308 pages **Order code NE39** **£24.99**

MICROCONTROLLER COOKBOOK
Mike James
240 pages **Order code NE26** **£36.99**

BOOK ORDERING DETAILS

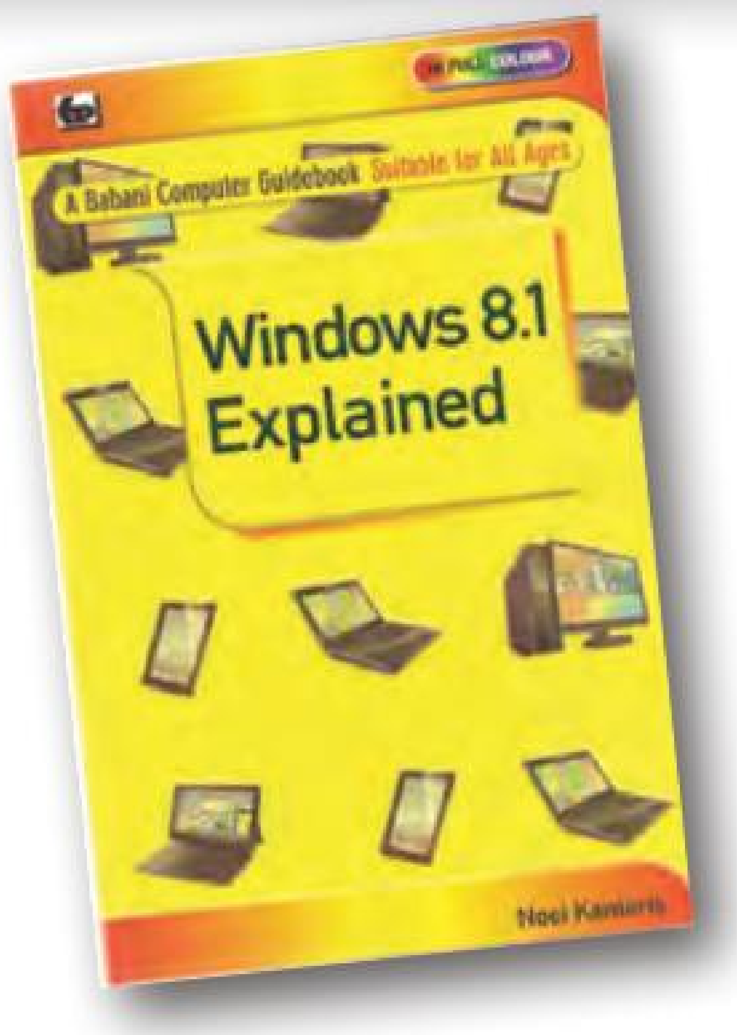
All prices include UK postage. For postage to Europe (air) and the rest of the world (surface) please add £3 per book. Surface mail can take up to 10 weeks to some countries. For the rest of the world airmail add £4 per book. CD-ROM prices include VAT and/or postage to anywhere in the world. Send a PO, cheque, international money order (£ sterling only) made payable to **Direct Book Service** or card details, Visa, Mastercard or Maestro to: **DIRECT BOOK SERVICE, WIMBORNE PUBLISHING LIMITED, 113 LYNWOOD DRIVE, MERLEY, WIMBORNE, DORSET BH21 1UU**.

Books are normally sent within seven days of receipt of order, but please allow 28 days for delivery – more for overseas orders. *Please check price and availability (see latest issue of* Everyday Practical Electronics*) before ordering from old lists.*

For a full description of these books please see the shop on our website.
Tel 01202 880299 Fax 01202 843233. E-mail: dbs@wimborne.co.uk

Order from our online shop at: www.epemag.com

FULL COLOUR COMPUTING BOOKS



WINDOWS 8.1 EXPLAINED

Windows 8.1 is the latest version of Microsoft's operating system. It is installed on all new Windows Desktop. Laptop and X86 tablet computers and is also available as a free upgrade. Whether you choose to use the touch screen Tile interface or the mouse operated Desktop interface, a good working knowledge of the operating system is essential to get the most from your computer and this book will help you to do just that.

The book applies to Windows 8.1, Windows 8.1 Pro and the vast majority of Windows 8.1 Enterprise. Also parts of the book should be applicable to windows RT 8.1 which is built on the same foundation as Windows 8.1 but is a restricted version designed specifically for ARM tablets.

Among the many topic covered are: An overview of the Tile Interface, Desktop, Taskbar, Tray Notification Area, Charms bar and running Apps; managing Windows settings, personalising your PC and creating User Accounts; using the Desktop File Explorer, SkyDive, Internet Explorer and the E-mail App; working with and organising digital photographs, using Media Player to play and store music and to burn CDs and installing Media Center to play DVDs; connecting to wireless networks, setting up a HomeGroup, sharing a printer and networked PCs; using mobility tools to keep your laptop running while away from home; accessibility features should you have dexterity or eyesight problems; keeping your computer healthy and backing up important files; And much more besides…..

180 Pages **Order code BP747** **£10.99**

IN FULL COLOUR
A Babani Computer Guidebook Suitable for All Ages
Kindle Fire HDX Explained
Noel Kantaris

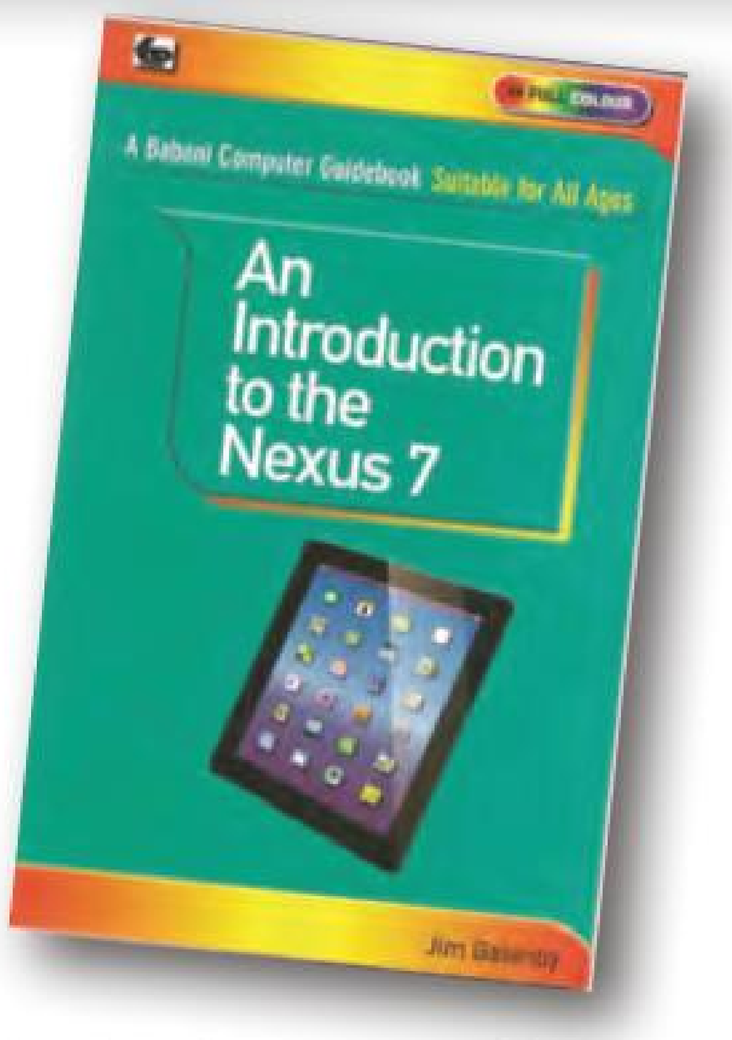
KINDLE FIRE HDX EXPLAINED

This book is written to help users get to grips, quickly and easily, with the amazing Kindle Fire HDX tablet. You will be guided through the configuration and use of the Kindle Fire HDXs facilities and functions. This book was written using the 7" HDX but it is also applicable to the 8.9" model.

Among the many topics covered are: An overview of the Kindle Fire HDX. Charging and setting up, connecting to a Wi-Fi network, registering the device and connecting to Social Networks; setting up and using the 1-Click Amazon account for buying and downloading books, music and other content that you have searched for. Explaining the use of the Carousel. Starting screen Apps. Web and Device settings and the Mayday facility; browsing the web with Silk Internet explorer, using Bookmarks and History, printing web pages, documents and messages; connecting to a server to send and receive e-mail messages, using and saving attachments. Creating and organising your Contacts and Calendar appointements; using the Kindle Fire camera to take photos and videos. Watching TV, listening to music you bought, imported and from the radio. Using the X-ray feature with books and other media; Using the OfficeSuite to view your documents, upgrading to OfficeSuite Professional 7 to allow both viewing and creation of Word documents. Excel spreadsheets and PowerPoint presentations. And more besides...

This book will help you acquire the skills needed to understand and make the most of your Kindle Fire HDX.

118 Pages **Order code BP743** **£8.99**


IN FULL COLOUR
A Babani Computer Guidebook Suitable for All Ages
An Introduction to the Nexus 7
Jim Gatenby

AN INTRODUCTION TO THE NEXUS 7

This book is intended for the new user of the Nexus 7, although much of it will also apply to the Nexus 10. It is easy to understand being written in plain English and avoiding technical jargon wherever possible.

Among the many useful topics covered are: An overview of the main features of the Nexus 7; setting up the Nexus 7; charging the battery; connecting to the Internet and signing up for Gmail; touch-screen operation and navigating around the various screens; installing Apps from the Google Play Store; setting a password and other precautions to keep your files safe; connecting accessories such as a USB Drive, mouse and keyboard; enjoying entertainment such as eBooks, games, music and videos; searching the Internet, including speaking in keywords; using e-mail, Skype and social networking; installing the free Google Drive app to save your documents in the cloud; using Google Docs free word processing and spreadsheet software; printing a document using Google Cloud Print, Exporting Nexus 7 files to laptop and desktop computers; and much more besides….

Even if you are a complete beginner, this book will help you to easily acquire the skills needed to understand and make the most of the Nexus 7.

118 Pages **Order code BP744** **£8.99**

HOW TO FIX YOUR PC PROBLEMS
R.A. Penfold

128 pages **Order code BP705** **£8.49**

AN INTRODUCTION TO WINDOWS VISTA
P.R.M. Oliver and N. Kantarris

120 pages **Order code BP703** **£8.49**

COMPUTING WITH A LAPTOP FOR THE OLDER GENERATION
R.A. Penfold

120 pages **Order code BP702** **£8.49**

AN INTRODUCTION TO EXCEL SPREADSHEETS
Jim Gatenby

18 pages **Order code BP701** **£8.49**

80
The Basic Soldering Guide
Learn to solder successfully!
Alan Winstanley
ANTEX

THE BASIC SOLDERING GUIDE HANDBOOK

LEARN TO SOLDER SUCCESSFULLY!
ALAN WINSTANLEY

The No.1 resource to learn all the basic aspects of electronics soldering by hand.

With more than 80 high quality colour photographs, this book explains the correct choice of soldering irons, solder, fluxes and tools. The techniques of how to solder and desolder electronic components are then explained in a clear, friendly and non-technical fashion so you'll be soldering successfully in next to no time! The book also includes sections on Reflow Soldering and Desoldering Techniques, Potential Hazards and Useful Resources. Plus a Troubleshooting Guide.

Also ideal for those approaching electronics from other industries, the Basic Soldering Guide Handbook is the best resource of its type, and thanks to its excellent colour photography and crystal clear text, the art of soldering can now be learned by everyone!

86 Pages **Order code AW1** **£9.99**

BOOK ORDER FORM

Full name: ....

Address: ....

....

....

.... Post code: .... Telephone No: ....

Signature: ....

☐ I enclose cheque/PO payable to DIRECT BOOK SERVICE for £ ....

☐ Please charge my card £ .... Card expiry date..

Card Number .... Maestro Issue No.............................

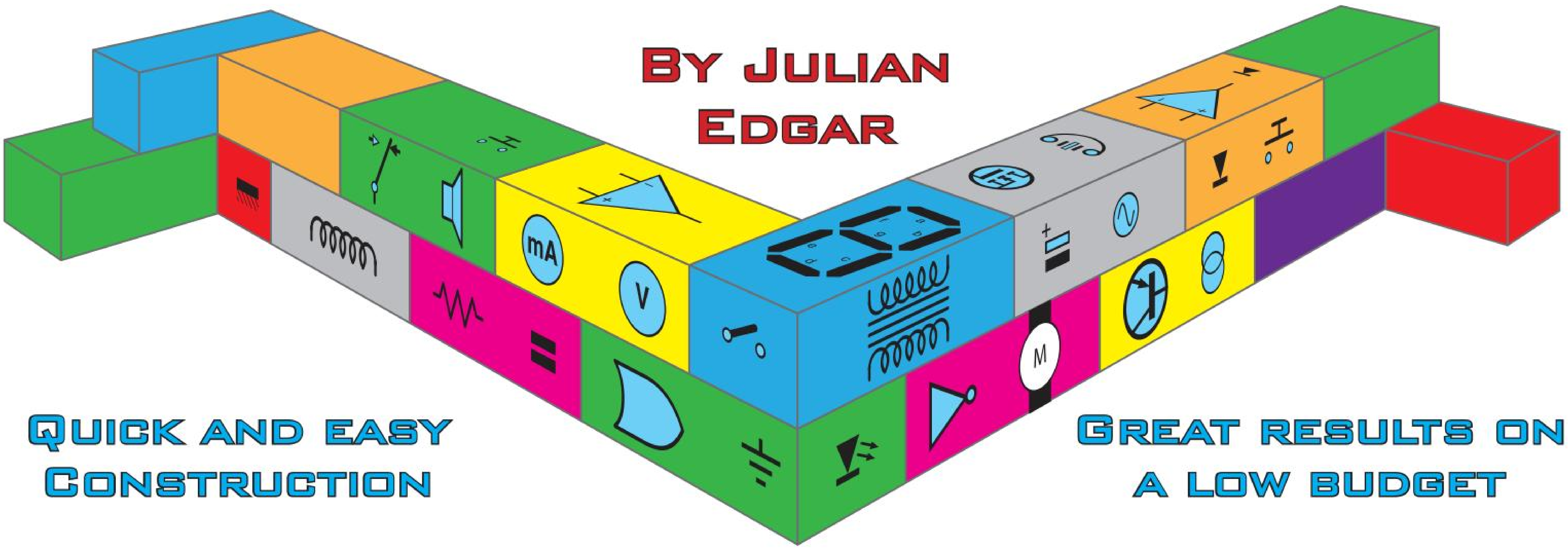
Valid From Date .... Card Security Code .... (The last three digits on or just below the signature strip)

Please send book order codes: ....

....

Please continue on separate sheet of paper if necessary

Electronic Building Blocks



By Julian Edgar

Quick and easy Construction

Great results on a low budget

New control system for a spot welder

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! They represent the best value we can find in today's electronics marketplace!

This month, I'd like to cover something a little different. Rather than look at individual products purchased on eBay (or other online sites), I'd like to cover a complete project built from parts sourced very cheaply to revolutionise the usefulness of an old workshop machine

It's not a project that each of you will be rushing off to do for yourself, but it's still interesting for two reasons. First, it shows just what is possible with such a vast range of electronic modules and components now available; and second, it shows that projects that would have once not been viable because of cost have now not only become viable, but cheap! Such is the change also in the economics of our hobby over the last few years.

The project

I have an extensive home workshop with a variety of metal- and wood-working tools. For example, I am lucky enough to own oxy-acetylene, MIG and TIG welders. However, I decided that additionally I wanted a spot welder, but found that these welders have not come down in price in the way that other welders have. (And what is a spot welder? See the accompanying box.)

I therefore decided to buy an old, second-hand spot welder. My machine probably dates back to the 1950s, and weighs a considerable 76kg when mounted on its stand – see Fig.1. Cost was £350, about half the price of a new welder with similar secondary current.

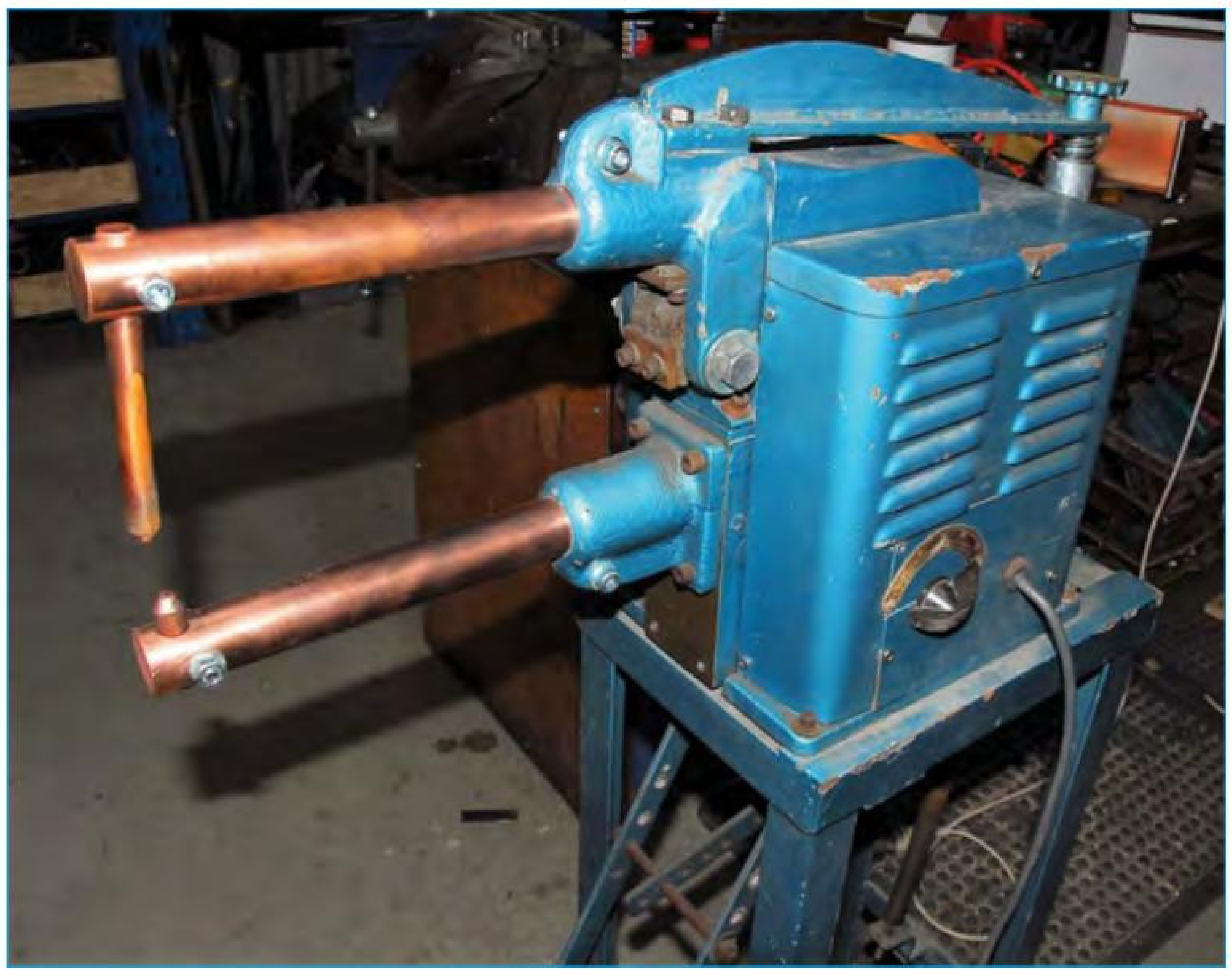


Fig.1. This old spot welder has a high current capability and is built like a tank. However, as purchased, the welding duration was controlled by a mechanical switch operated by a foot pedal. This made setting the welding duration a bit hit and miss.

The old welder was designed so that when the foot pedal was pushed down, the electrodes clamped the workpiece. Press further, and a switch was triggered that activated the current. Because the arms were closed by a foot pedal, the welding time was set only by movement of the operator's foot.

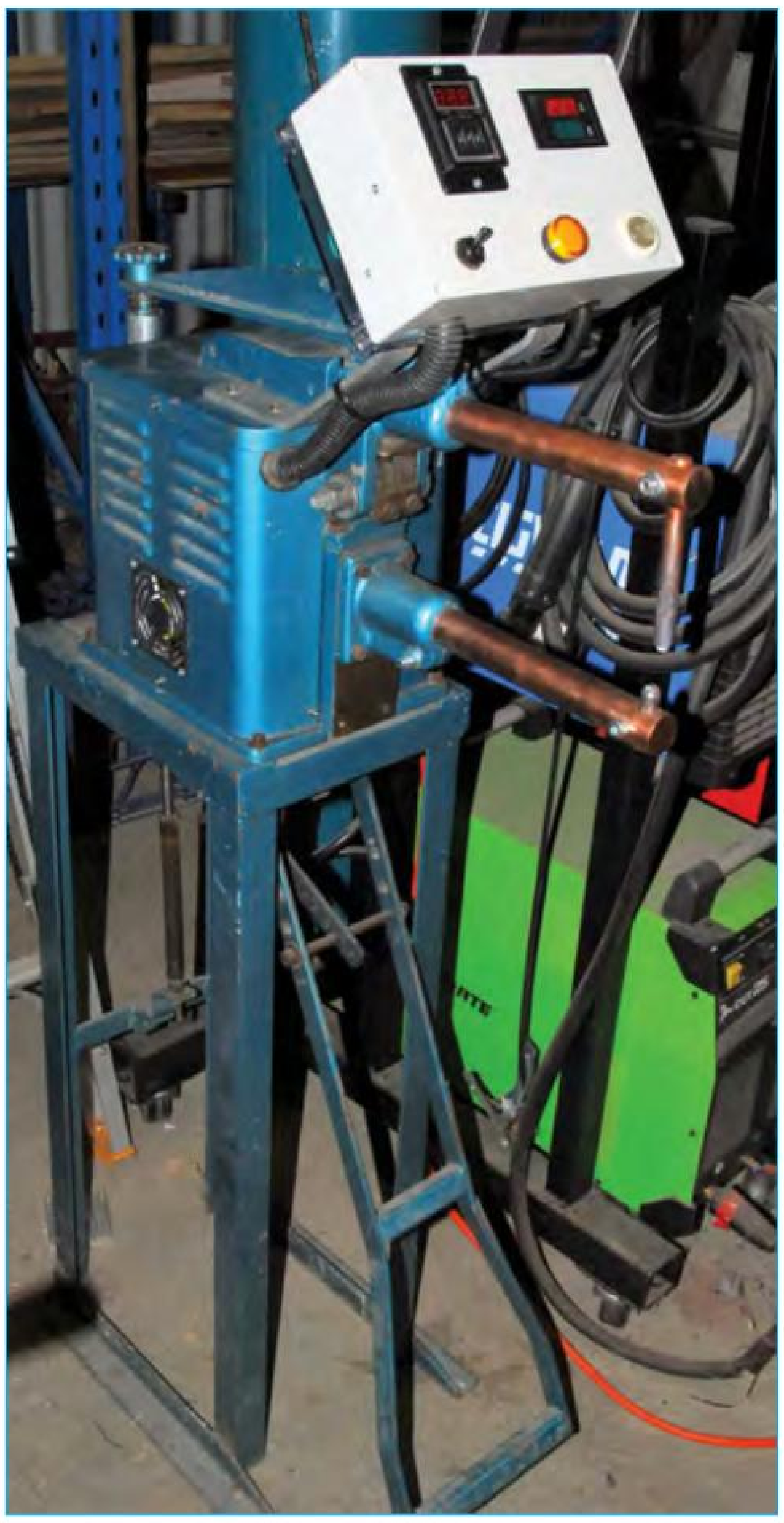


Fig.2. The finished welder with the new control panel, positioned above the welding electrodes. The panel incorporates a digital timer, digital mains voltage and current meters, a 'welding occurring' pilot light, and a manual weld over-ride switch.

In spot welding, the duration of the weld time is very important. For example, when welding thin gauge metal, too short a weld time (eg, 0.2s) gives a weak weld. On the other hand, too long a weld time (eg, 0.5s) and the metal becomes overheated, with liquid metal expelled from the weld. I

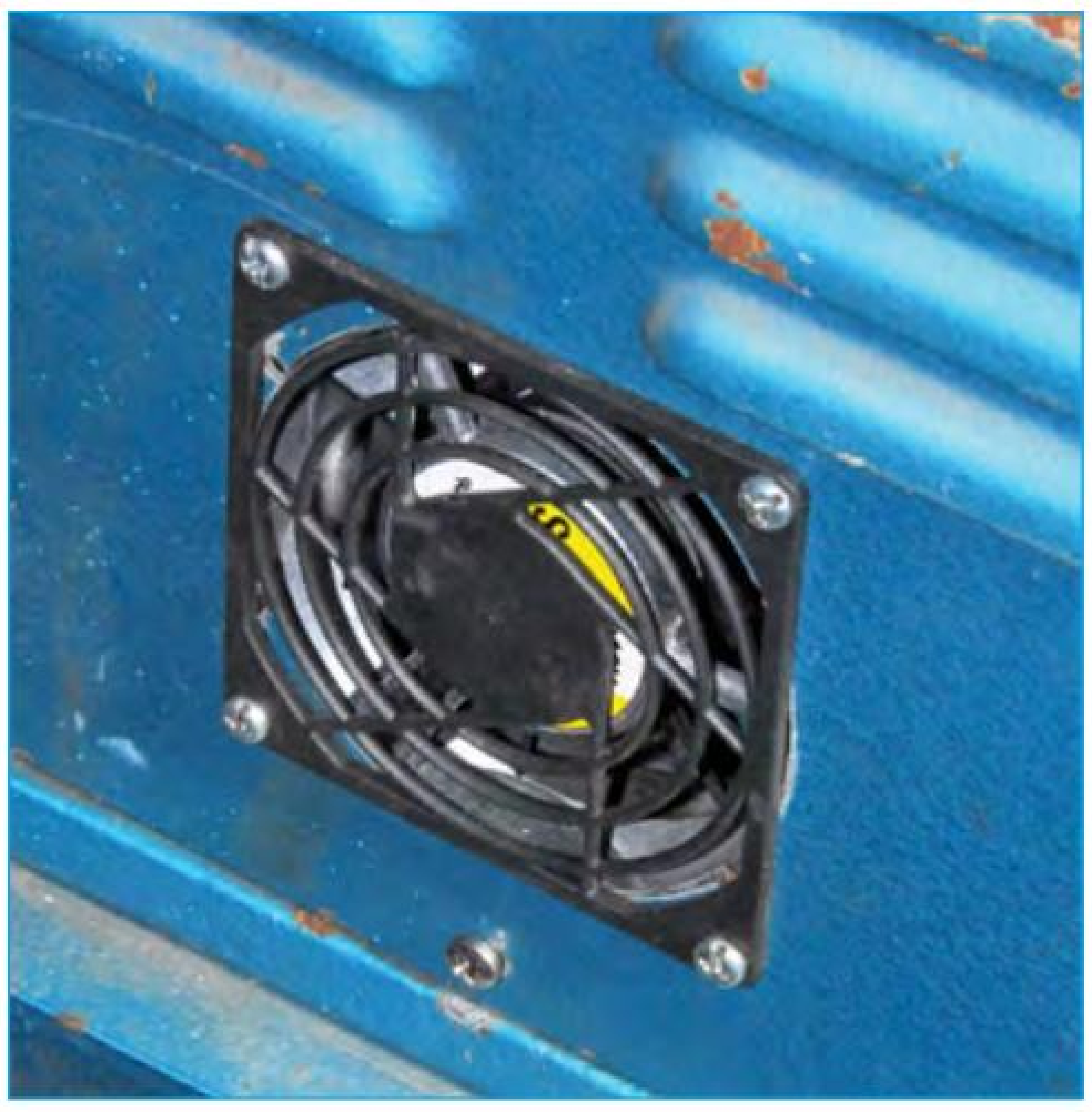


Fig.3. A fan was added to circulate air around the transformer. It's funny to think that when the welder was produced over 50 years ago, cooling fans such as these were unknown!

What is spot welding?

Spot welding, also known as resistance spot welding, is one of the oldest of electrical welding processes. Elihu Thompson, an English-born American engineer, invented spot welding, with his major patent in this area awarded in 1885.

The main element of most current spot welders is a large transformer. The transformer comprises a primary winding (connected to mains power) and a secondary winding, connected to the welding electrodes. The transformer reduces mains voltage (eg, 240V) to a much lower voltage (eg 2V). At the same time, the available current at the welding electrodes increases massively. For example, if the current drawn from the mains socket is 15A, and the voltage step-down ratio is 120 times, then the current available at the welding tongs is 120 times greater, or 1800A! (This assumes a perfectly efficient transformer, but you get the idea.)

When such high current is passed through the sandwich of sheet metals clamped between the welding electrodes, the higher resistance that is present at the join between the two metals causes heat to be generated. That heat is sufficient to create a 'nugget' of molten material that, when it cools, has joined the two sheets. No metal is added and the weld is actually within the join of the two sheets, rather than external to them.

Many steel consumer goods use spot welding. For example, cars manufactured from steel use numerous spot welds to hold together the body parts. In fact, a typical bare car body shell contains about 5000 spot welds, and some car factories produce more than 20 million spot welds per week.

therefore decided to add an adjustable electronic timer that would allow the welding duration to be accurate and repeatable, as shown in Fig.2.

These welders draw a lot of current from the mains and develop secondary currents measured in thousands of amps. So what would happen if you went on a welding frenzy? The answer would be the welder's transformer would get hot. The fan shown in Fig.3 was therefore added to cool the transformer.

Finally, with these simple transformer-type spot welders, the amount of secondary current (the current that does the welding) depends on the mains voltage, as received by the welder. And because of the very high current draw, the voltage drop can be considerable. Throw in that the mains voltage where I live (rural Australia) can vary by 20V or more (and that's off-load!), and I decided to add a mains voltage display. When looking for one of those, I realised that I could also add a mains current display at little additional cost – so I bought a combined voltage/current meter, as shown in Fig.4.

In detail

The major electronic changes are:

- New solid-state relay used to control mains-power switching
- Length of weld time controlled by a user-adjustable digital timer
- Micro-switch automatically triggers the timer when full electrode clamping pressure has been reached
- Over-ride pushbutton can be used by the operator to give a manual weld time
- New control panel has main on/off switch, 'welding occurring' pilot light, manual weld over-ride pushbutton, adjustable digital timer, and combined mains voltage and mains current meters.
- Small power supply generates 12V for solid-state relay control, digital timer and pilot light.

Let's take the major parts one at a time.

1. Solid-state relay

When set to its highest power, the welder can draw up to 28A, and it takes a 38A gulp when first starting a weld. These are very high currents at 240V, and would cause problems to most mechanical relays. So instead of a mechanical relay, a Crydon TD2425 solid-state relay was used to switch mains current (Fig.5). This relay is rated at 25A continuous and has a maximum surge current rating of 250A. While the welder can draw more than 25A, it does not do so continuously, so this relay should be fine. Similar relays are available on eBay for under £10.

Given that welding occurs for such short periods, I wondered if a heat sink would even be necessary for the solid state relay, but some load-testing of the bare relay showed that it was getting warm. To address this, I decided to mount the relay on a thick aluminium plate that would act as a heat sink.

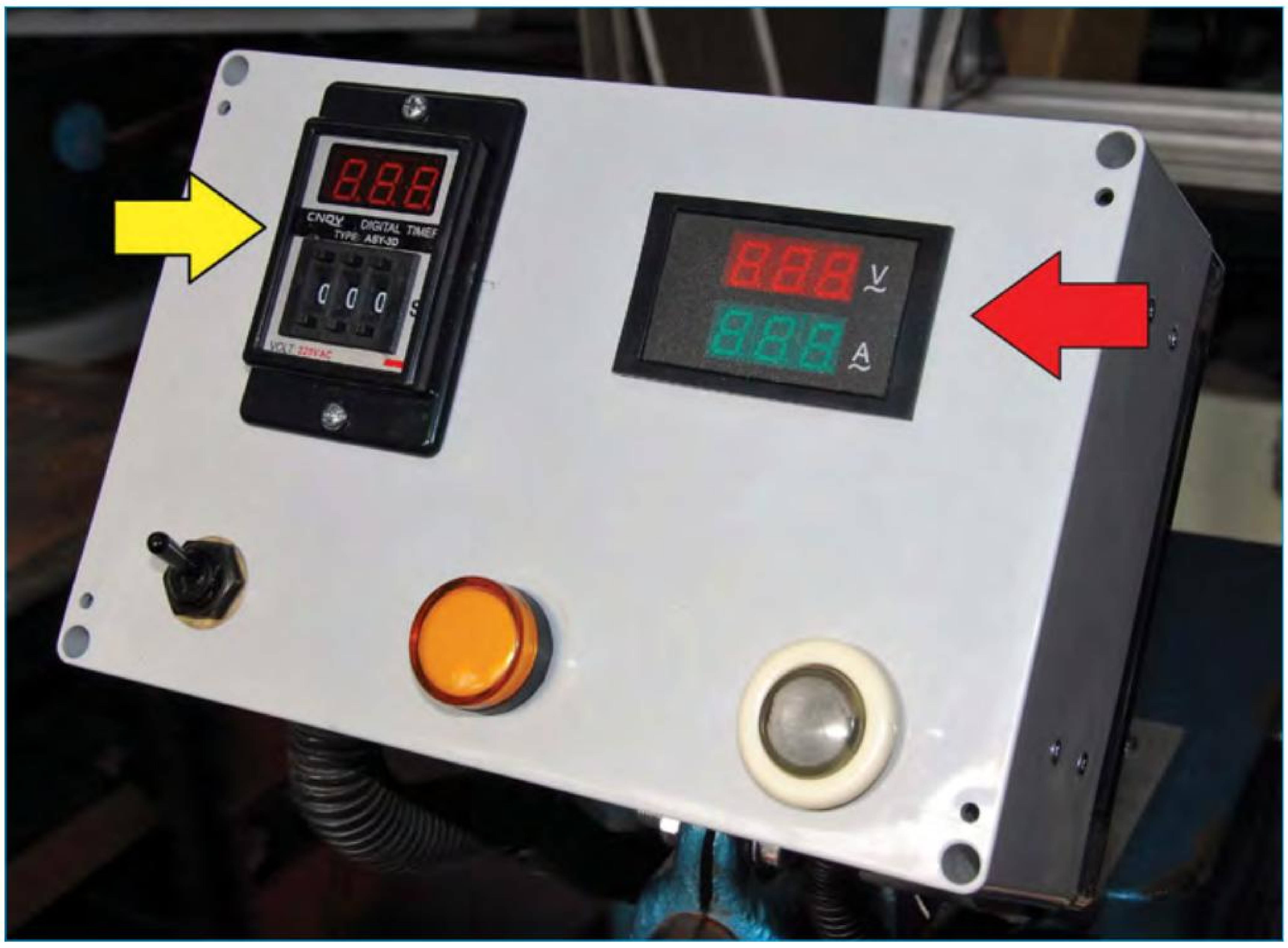


Fig.4. The new control panel for the welder. The yellow arrow points to the adjustable digital timer that sets the period during which welding current flows. The red arrow shows the mains voltage and current meters. Across the bottom are the on/off switch, the 'welding occurring' pilot lamps, and the manual over-ride welding pushbutton. Note that despite its 220V label, the timer is actually a 12V model.

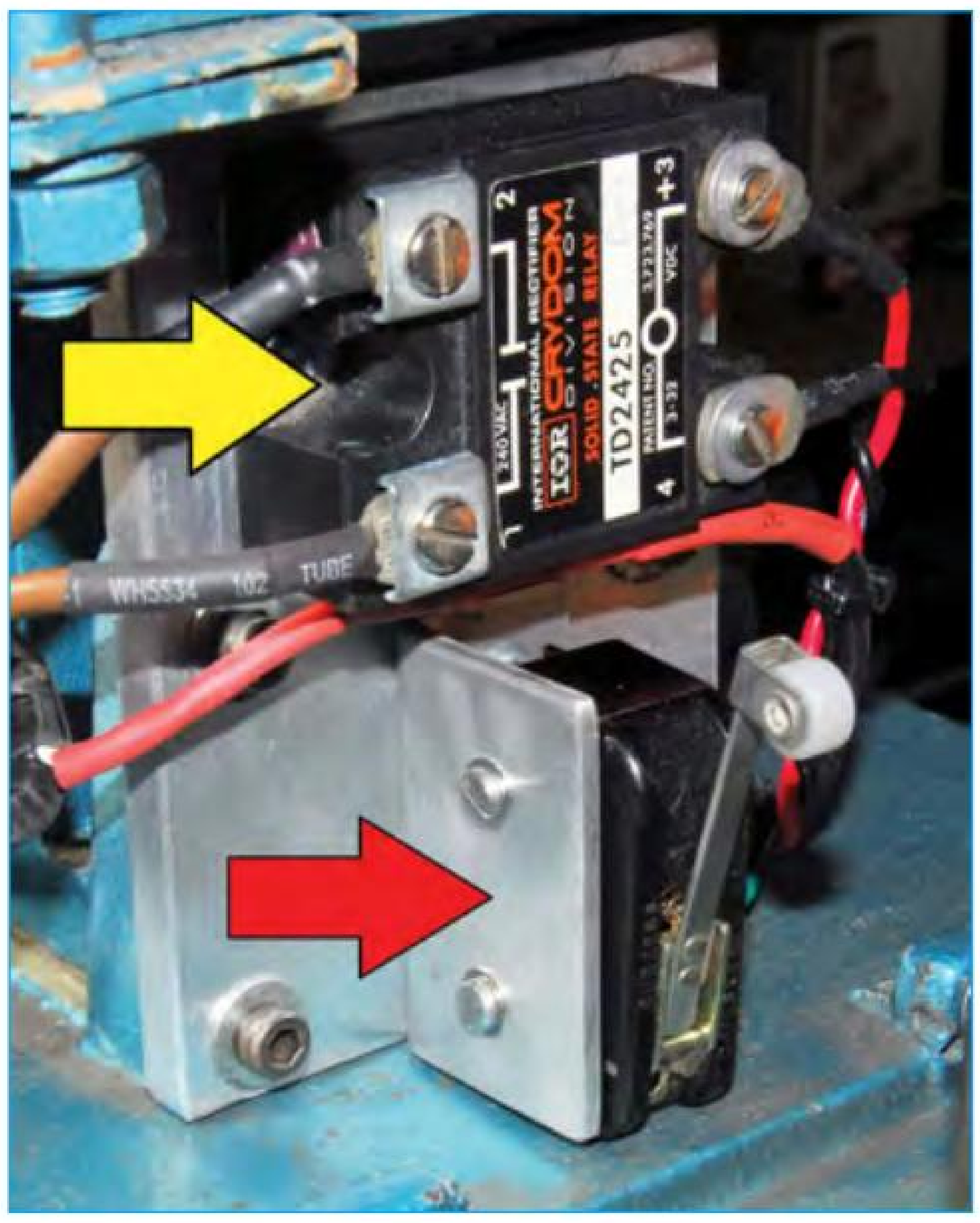


Fig.5. This photograph shows the welder with its rear cover removed. The new solid-state relay (yellow arrow) controls the primary current flow to the transformer. Note the heat sink for the relay provided by the thick aluminium plate. The red arrow points to the micro-switch that is triggered when the foot pedal achieves full electrode clamping pressure. This switch then activates the welding timer.

The solid state module is operated by a low-voltage, low-current source – 12V in this case.

2. Micro-switch

A micro-switch is the main trigger for the welding current to flow. In the original welder, the movement of the foot pedal operated a heavy-duty switch. This switch comprised big chunks of copper, and worked directly on the mains power supply to the transformer. To replace this, the original switch was removed and was replaced (working in much the same position) by the micro-switch, triggered by an adjustable cam plate that moves with the foot pedal. I had the micro-switch on the shelf, but similar ones cost about £2.

The micro-switch feeds power to the digital timer. Therefore, when the switch is tripped, the digital timer's output is activated, so switching on the solid state relay (and therefore the welding current) and starting the timer countdown. When the timer reaches zero, the sold-state relay is turned off, ending the weld current period.

3. Digital timer

The heart of the new control system is a digital timer. Available very cheaply on eBay (search for 'AC/DC 12V 8 Pin DPDT 0.01-9.99 Second 9s Time Delay Relay Timer Black ASY-3D'). The timer uses thumbwheel adjustable switches to set the output time anywhere from 0.01s to 9.99s. At the time of writing, eBay item 121781422816, which costs just £7 including postage. (Note that an 8-pin socket is required for the timer – it's purchased separately.)

When the timer is powered-up by the micro-switch, the internal output relay is energised. The digital display then counts down the timed period and when this has ended, the output relay is turned off.

Well that was the theory! Unfortunately, the timer cannot be configured in this way. Instead, the nearest function is that the relay output of the timer is as follows: on when you'd like it to be off, and off when you'd like it to be on. To achieve the required reversal in function, an automotive 12V 'normally closed' relay (about £3) was added to the circuit.

With the timer and additional relay working, the internal output relay of the timer activates the external normally closed relay, that in turn triggers the solid-state relay, so feeding mains to the transformer (and finally a much larger secondary current to the welding electrodes). It does this for only the user-selectable timed period.

In addition, the output of the timer switches on the 'welding occurring' pilot light – this light is wired in parallel with the solid-state relay control input. A 12V LED pilot light is used for this function.

In parallel with the additional relay's output is the manual over-ride welding push-button. With the timer set to 0, this allows the operator to determine the welding time – when the micro-switch is activated by the foot pedal, welding time continues for as long as a finger is on the button.

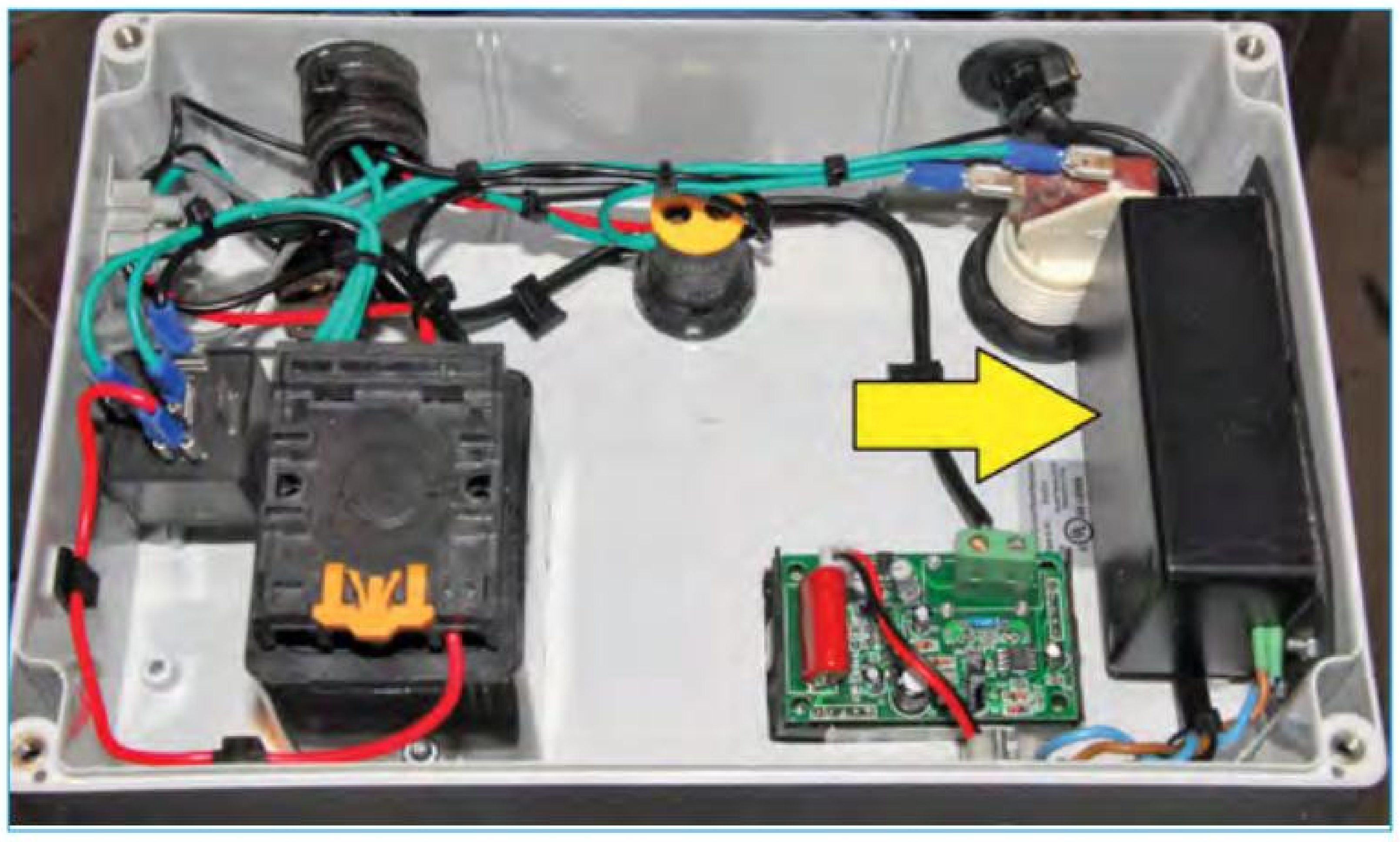


Fig.6. This view shows the inside of the new control panel. The arrow points to the rehoused 12V plugpack that supplies power for the electronics. At the far left is the additional relay required to reverse the timer's control logic.

4. 12V power supply

12V power for the solid-state relay control, digital timer, pilot light and cooling fan is provided by the guts of a 12V regulated switch-mode plugpack, mounted within a new insulated plastic box. The plug pack was one of the salvaged ones I have on the shelf.

5. Mains current and voltage display

The combined volt and amp meter is available on eBay – search under 'AC 80-300V 100A LED Panel Digital Ammeter Voltmeter Volt Amp Meter 110 220-240V'. At the time of writing, eBay item 322130836484, which costs just £7, including postage.

The same leads that power the meter monitor the voltage. The current is monitored by means of a Hall-effect sensor that comprises a ring through which one of the mains power conductors is passed. (Note that there is no electric connection between this monitoring device and the conductor.) The output of the Hall-effect sensor is then connected to the on-board socket of the display. I used shielded cable to make this connection.

Conclusion

The changes have revolutionised the welder. How? In some ways, not as I expected!

First, the use of the electronic timer means that, especially when weld times are short, excellent results can be obtained. My test for this is to weld two mild steel roofing nails together. This welding requires precise timing – because of their low thermal mass, too long a welding period and the nails completely melt – but too short and the weld is not strong. However, with the use of the timer, consistent welds can be made each time on tricky materials such as these.

Second, the voltage and current displays have proved to be more useful than expected. If the contact between the materials being welded is not effective (for example, there is residual paint, plating or corrosion) then the current flow shown on the meter is much lower than normal. This immediately alerts the operator that the weld is going to be poor.

Last, the cooling fan keeps the transformer temperature noticeably lower than occurred previously.

Not long ago, a project such as described here would have cost three or four times what I paid – making the whole welder modification a project not worth pursuing. But for an all-up project cost of around £40, the results are fantastic.

Electronics & Robotics for Makers

TinyDuino

As powerful as the Arduino Uno but smaller than a 2 pence coin.

Complete with a wide and growing range of TinyShields - where will your next project take you?

All the power of the Arduino in a fraction of the space, great for building intelligence in to your projects.

STEMTera Breadboard

A breadboard with built-in Arduino! The breadboard has a total of 41 I/O pins of which 9 provide PWM. Pin-to-pin compatible with **Arduino UNO R3** shield. The bottom cover is Lego® compatible and will fit base plates and bricks - great for Robotics and Animatronics.

Fully **Arduino IDE** compatible and built with strong ABS plastic and is available in a range of colours.

Edison Robot

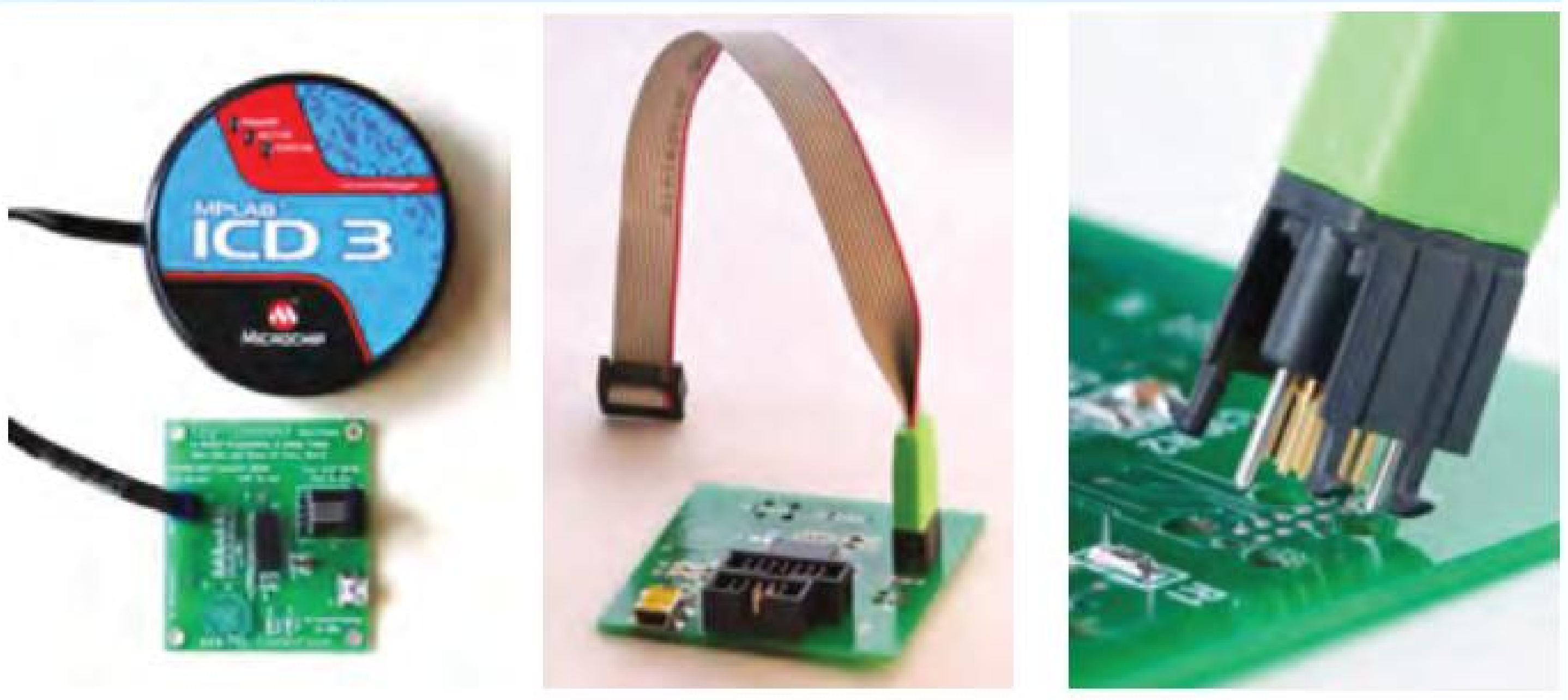
Edison is great for schools and hobbyists alike to teach kids robotics and programming on any computer, tablet or phone.

Edison is a LEGO compatible robot which means your kids can let their imagination run wild. Why not make a remote control LEGO

There's a lot that one Edison Robot can do, imagine what your kids can do with a team of them working together!

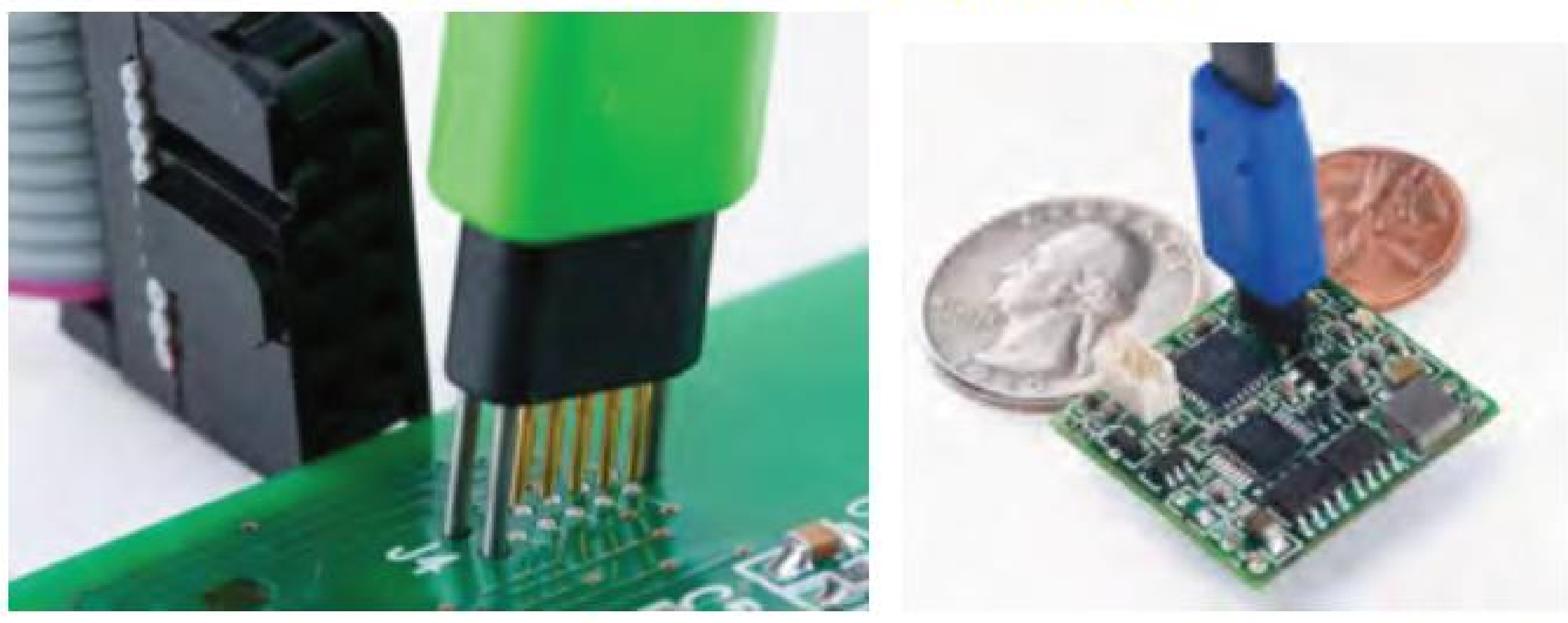
Supporting Education
Supporting *Makers*
iCSAT
www.eshop.icsat.co.uk

Tag-Connect



JTAG Connector Plugs Directly into PCB!!

No Header!   No Brainer!



Our patented range of Plug-of-Nails™ spring-pin cables plug directly into a tiny footprint of pads and locating holes in your PCB, eliminating the need for a mating header.   Save Cost & Space on Every PCB!!

Solutions for: PIC . dsPIC . ARM . MSP430 . Atmel . Generic JTAG . Altera Xilinx . BDM . C2000 . SPY-BI-WIRE . SPI / IIC . Altium Mini-HDMI . & More

www.PlugOfNails.com

Tag-Connector footprints as small as 0.02 sq. inch (0.13 sq cm)

pico® Technology

HIGH-PERFORMANCE
8-CHANNEL
OSCILLOSCOPE

12-bit resolution
20 MHz bandwidth
8 channels
256 MS buffer memory

The PicoScope 4824 is a low-cost, portable solution for multi-input applications. With 8 high-resolution analog channels you can easily analyze audio, ultrasound, vibration, power and timing of complex systems.

The PicoScope 4824 has the power and functionality to deliver accurate results. It also features deep memory to analyze multiple serial buses such as UART, I²C, SPI, CAN and LIN plus control and driver signals.

Also features:
- High-performance arbitrary waveform generator
- Advanced digital triggers
- Serial bus decoding
- SuperSpeed USB 3.1 Gen 1 interface
- Windows, Mac and Linux software

NEW Software Update
Get the latest software release at
www.picotech.com/library/picoscope/picoscope-release-6.12.5

For more information please visit
www.picotech.com/PS513

Email: sales@picotech.com. Errors and omissions excepted. Prices are correct at the time of publication. Sales taxes not included. Please contact Pico Technology for the latest prices before ordering.

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

PROJECT TITLE	ORDER CODE	COST
NOV '15		
The Currawong – Part 1		
– Main Board	01111141	£47.20
– Front Panel	01111142	£24.75
– Rear Panel	01111143	
48V Dual Phantom Power Supply	18112141	£9.37
Programmable Mains Timer With Remote Switching		
– Main Board	19112141	£11.80
– Front Panel	19112142	£16.40
DEC '15		
TDR Dongle For Oscilloscopes	04112141	£7.20
High-Energy Multi-Spark CDI For Performance Cars	05112141	£11.80
JAN '16		
Isolating High Voltage Probe For Oscilloscopes	04108141	£11.80
The Currawong – Part 3		
– Remote Control Board	01111144	£6.95
FEB '16		
Spark Energy Meter – Main Board	05101151	£20.75
– Zener Diode Board	05101152	£7.50
– Calibrator Board	05101153	
APRIL '16		
Appliance Insulation Tester	04103151	£11.80
– Front Panel	04103152	£11.80
Low Frequency Distortion Analyser	04104151	£7.50
MAY '16		
2-Channel Balanced Input Attenuator for Audio Analysers and Digital Scopes		
– Main Board	04105151	£16.40
– Front Panel	04105152	£20.75
– Rear Panel	04105153	
Appliance Earth Leakage Tester		
– Main Board	04203151	£16.40
– Insulation Board	04203152	
– Front Panel	04203153	£16.40
4-Output Universal Voltage Regulator	18105151	£7.50
JUNE '16		
Infrasound Snooper	04104151	£7.50
Audio Signal Injector and Tracer	04106151	£9.64
– Shield Board	04106153	£7.48
– Demodulator Board	04106152	£5.36
Champion Preamp	01109121/22	£8.29
JULY '16		
Driveway Monitor – Detector Unit	15105151	£11.80
– Receiver Unit	15105152	£7.50
USB Charging Points	18107151	£5.00
AUG '16		
Low-cost Resistance Reference	04108151	£5.36
USB Power Monitor	04109121	£12.00
SEPT '16		
LED Party Strobe	16101141	£9.80
Speedo Corrector	05109131	£12.00
OCT '16		
Arduino-Based USB Electrocardiogram	07108151	£9.79
100W Switchmode/Linear Bench Supply – Part 2	18104141	£20.83
NOV '16		
Fingerprint Access Controller – Main Board	03109151	£12.88
– Switch Board	03109152	
DEC '16		
Universal Loudspeaker Protector	01110151	£12.88
9-Channel Infrared Remote Control	15108151	£16.42
Revised USB Charger	18107152	£5.36
JAN '17		
High-performance Stereo Valve Preamplifier	01101161	£17.75
High Visibility 6-Digit LED Clock	19110151	£16.42
FEB '17		
Solar MPPT Charger/Lighting Controller	16101161	£17.75
Turntable LED Strobe	04101161	£7.60
MARCH '17		
Speech Timer for Contests & Debates	19111151	£16.42
APRIL '17		
Microwave Leakage Detector	04103161	£8.00
Arduino Multifunctional 24-bit Measuring Shield	04116011	£17.75
– RF Head Board	04116012	
Battery Pack Cell Balancer	11111151	£9.00

*** See NOTE left regarding PCBs with eight digit codes ***

Please check price and availability in the latest issue.
A large number of older boards are listed on, and can be ordered from, our website.

Boards can only be supplied on a payment with order basis.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at:
www.epemag.com

PCB MASTERS

PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers – email **fay.kearn@wimborne.co.uk** stating which masters you would like.

EPE PRINTED CIRCUIT BOARD SERVICE

Order Code **Project** **Quantity** **Price**

. . . .

Name . . . .

Address . . . .

. . . .

Tel. No. . . . .

I enclose payment of £ . . . . (cheque/PO in **£ sterling only**)

to: **Everyday Practical Electronics**

Card No. . . . .

Valid From . . . . Expiry Date . . . .

Card Security No. . . . .

Signature . . . .

Note: You can also order PCBs by phone, Fax or Email or via the Shop on our website on a secure server:
http://www.epemag.com

CLASSIFIED
ADVERTISEMENTS

If you want your advertisements to be seen by the largest readership at the most economical price our classified page offers excellent value. The rate for semi-display space is £10 (+VAT) per centimetre high, with a minimum height of 2·5cm. All semi-display adverts have a width of 5.5cm. The prepaid rate for classified adverts is 40p (+VAT) per word (minimum 12 words).

All cheques, postal orders, etc., to be made payable to Everyday Practical Electronics. **VAT must be added**. Advertisements, together with remittance, should be sent to Everyday Practical Electronics Advertisements, 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU. Phone: 01202 880299. Fax: 01202 843233. Email: stewart.kearn@wimborne.co.uk. For rates and information on display and classified advertising please contact our Advertisement Manager, Stewart Kearn as above.

Everyday Practical Electronics reaches more UK readers than any other UK monthly hobby electronics magazine, our sales figures prove it.

We have been the leading monthly magazine in this market for the last twenty-seven years.

BOWOOD ELECTRONICS LTD

Suppliers of Electronic Components

www.bowood-electronics.co.uk

Unit 10, Boythorpe Business Park, Dock Walk, Chesterfield,
Derbyshire S40 2QR. Sales: 01246 200 222
Send large letter stamp for Catalogue

MISCELLANEOUS

KITS, TOOLS, COMPONENTS. S.A.E. Catalogue. SIR-KIT ELECTRONICS, 52 Severn Road, Clacton, CO15 3RB, **http://sir-kit.webs.com**

PIC DEVELOPMENT KITS, DTMF kits and modules, CTCSS Encoder and Decoder/Display kits. Visit **www.cstech.co.uk**

VALVES AND ALLIED COMPONENTS IN STOCK. Phone for free list. Valves, books and magazines wanted. Geoff Davies (Radio), tel. 01788 574774.

WEARDALE ELECTRONICS

FOR ELECTRONIC COMPONENTS
& ELECTRICAL PARTS Etc.
SEND YOUR WANTS LIST TO
steve@weardale-electronics.co.uk
or BROWSE MY EBAY SHOP AT
http://stores.ebay.co.uk/weardaleelectronics

NO ORDER TOO SMALL – PERSONAL SERVICE

CANTERBURY WINDINGS

UK manufacturer of toroidal transformers
(10VA to 3kVA)
All transformers made to order. No design fees.
No minimum order.
www.canterburywindings.co.uk
01227 450810

Instrumex Plans

Offers Lab Grade Test Equipment for the Electronic Home Builder

ACV-dB-VU Meter

All the Information You Need to Build 15 Popular and Exotic Test Instruments.
View Photos, Features and Specs.
First Group Ready to Download Now.

InstrumexPlans.com

ELECTRONIC & HARDWARE COMPONENTS

EVERYTHING FOR THE HOME CONSTRUCTOR

www.partridgeelectronics.co.uk

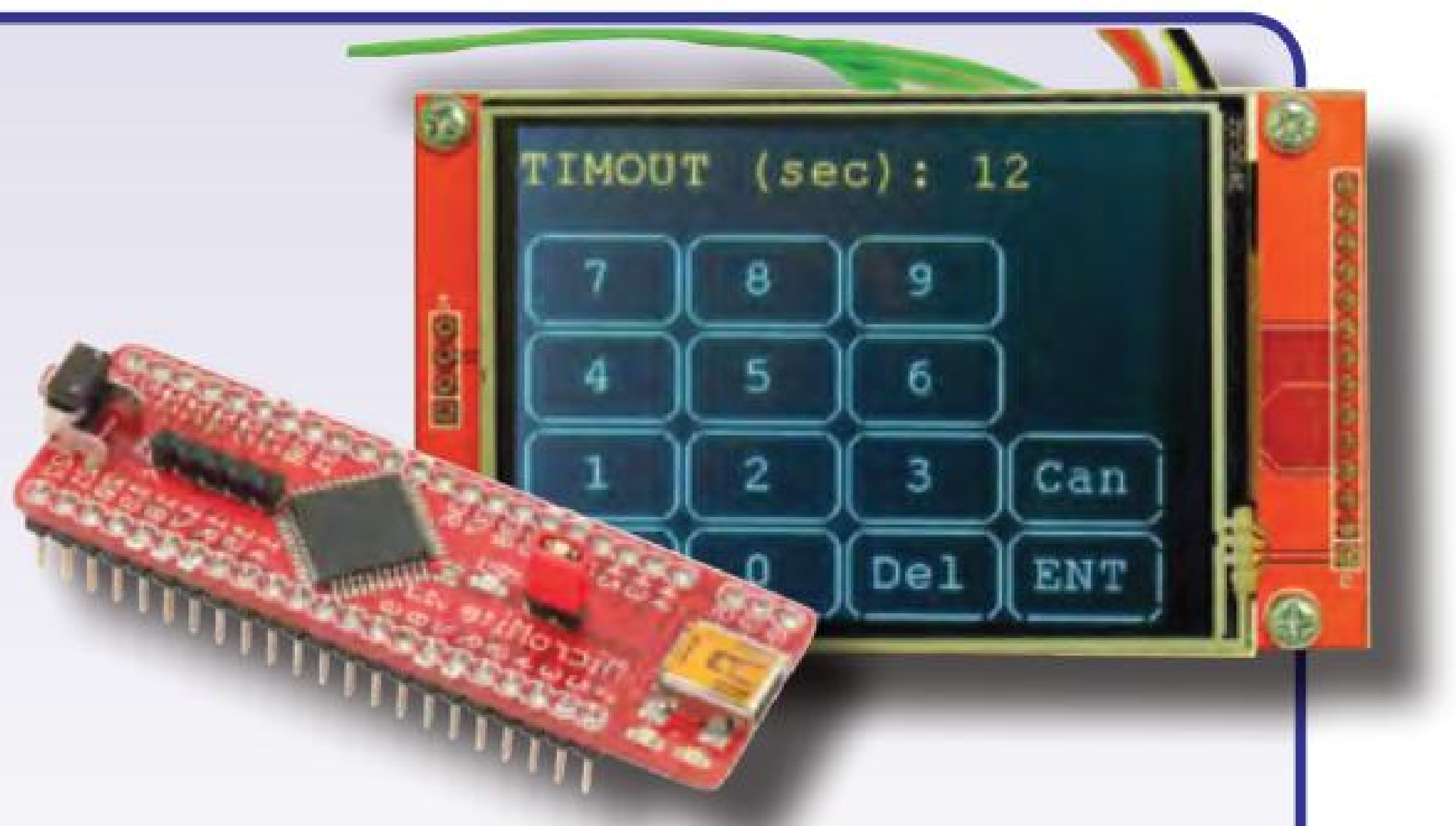
ADVERTISERS INDEX

BINARY DISTRIBUTION . . . . Cover (ii)
CRICKLEWOOD ELECTRONICS 45
ESR ELECTRONIC COMPONENTS 6
FUZE TECHNOLOGIES . . . . Cover (ii)
HAMMOND ELECTRONICS Ltd 16
iCSAT 69
JPG ELECTRONICS 72
LABNATION . . . . Cover (iv)
LASER BUSINESS SYSTEMS 51
MICROCHIP . . . . Cover (iii), 10 & 37
PEAK ELECTRONIC DESIGN 63
PICO TECHNOLOGY 69
POLABS D.O.O. 35
QUASAR ELECTRONICS 2/3
STEWART OF READING 51
TAG-CONNECT 69

ADVERTISEMENT OFFICES:
113 LYNWOOD DRIVE, MERLEY, WIMBORNE,
DORSET BH21 1UU
PHONE: 01202 880299
FAX: 01202 843233
EMAIL: stewart.kearn@wimborne.co.uk
WEB: www.epemag.com
For editorial address and phone numbers see page 7

Next Month

Content may be subject to change



The Micromite LCD BackPack

You've met the 'Mighty Micromite', now it's time for your first serious Micromite project – adding a touch-screen LCD. *The Micromite LCD BackPack* combines a full colour touch-sensitive LCD panel with a low-cost 32-bit microcontroller running a BASIC interpreter. It packs an incredible amount of power at an amazingly cheap price, and will leave you thinking up project after project where you could put it to good use.

Arduino Multifunction 24-Bit Measuring Shield – Part 2

The April issue introduced our new *Arduino-based Multifunction Meter* and gave the circuit details. Next month, we'll describe how to install the software and firmware that's needed to control it from a PC. Plus, we'll explain how to get it going, how to calibrate the various ranges (if you have the facilities) and how to use the finished unit.

Precision 230V/115V, 50/60Hz Turntable Driver

This *Precision Turntable Driver* will power belt-drive or idler-driven turntables with 230VAC at 50Hz or 115VAC at 60Hz. As a bonus, the turntable pitch is capable of being adjusted over a range of ±12%, which is great for music-teaching applications. It also enables you to adjust the music speed to obtain the correct number of beats to the minute for dancing applications.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *PIC n' Mix* and *Net Work.*

MAY '17 ISSUE ON SALE 6 APRIL 2017

WELCOME TO JPG ELECTRONICS
Selling Electronics in Chesterfield for 29 Years

Open Monday to Friday 9am to 5:30pm
And Saturday 9:30am to 5pm

- Aerials, Satellite Dishes & LCD Brackets
- Audio Adaptors, Connectors & Leads
- BT, Broadband, Network & USB Leads
- Computer Memory, Hard Drives & Parts
- DJ Equipment, Lighting & Supplies
- Extensive Electronic Components
  - *ICs, Project Boxes, Relays & Resistors*
- Raspberry Pi & Arduino Products
- Replacement Laptop Power Supplies
- Batteries, Fuses, Glue, Tools & Lots more...

T: 01246 211 202
E: sales@jpgelectronics.com
JPG Electronics, Shaw's Row,
Old Road, Chesterfield, S40 2RB
W: www.jpgelectronics.com

JPG Electronics

Retail & Trade Welcome • Free Parking • Google St View Tour: S40 2RB

Get the answer you've been looking for

PICs?
Can anyone help me?
Problem sourcing software?
General Electronics chat
I Can help!

Vist the EPE Chat Zone

www.epemag.com

Published on approximately the first Thursday of each month by Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Printed in England by Acorn Web Offset Ltd., Normanton, WF6 1TW. Distributed by Seymour, 86 Newman St., London W1T 3EX. Subscriptions INLAND: £23.50 (6 months); £43.00 (12 months); £79.50 (2 years). EUROPE: airmail service, £28.00 (6 months); £52.00 (12 months); £99.00 (2 years). REST OF THE WORLD: airmail service, £37.00 (6 months); £70.00 (12 months); £135.00 (2 years). Payments payable to "Everyday Practical Electronics'', Subs Dept, Wimborne Publishing Ltd. Email: subs@epemag.wimborne.co.uk. EVERYDAY PRACTICAL ELECTRONICS is sold subject to the following conditions, namely that it shall not, without the written consent of the Publishers first having been given, be lent, resold, hired out or otherwise disposed of by way of Trade at more than the recommended selling price shown on the cover, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of Trade or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.

Development Tool of the Month!

Multimedia Expansion Board II

Part Number
DM320005-2

Overview:

Multimedia Expansion Board II (MEB-II) is a highly integrated, compact and flexible development platform which works with PIC32MZ EF Starter Kit with Crypto Engine (DM320007-C), PIC32MZ EF Starter Kit (DM320007) and the MEB/MEB II UART-to-USB Adaptor Board (AC320101).

The MEB II supports detachable display boards allowing for a variety of resolutions and includes a 4.3″ WQVGA PCAP touch display daughter board. The kit also has an onboard 24-bit stereo audio codec, VGA camera, 802.11 b/g wireless module, Bluetooth HCI transceiver, temperature sensor, microSD slot and analog accelerometer.

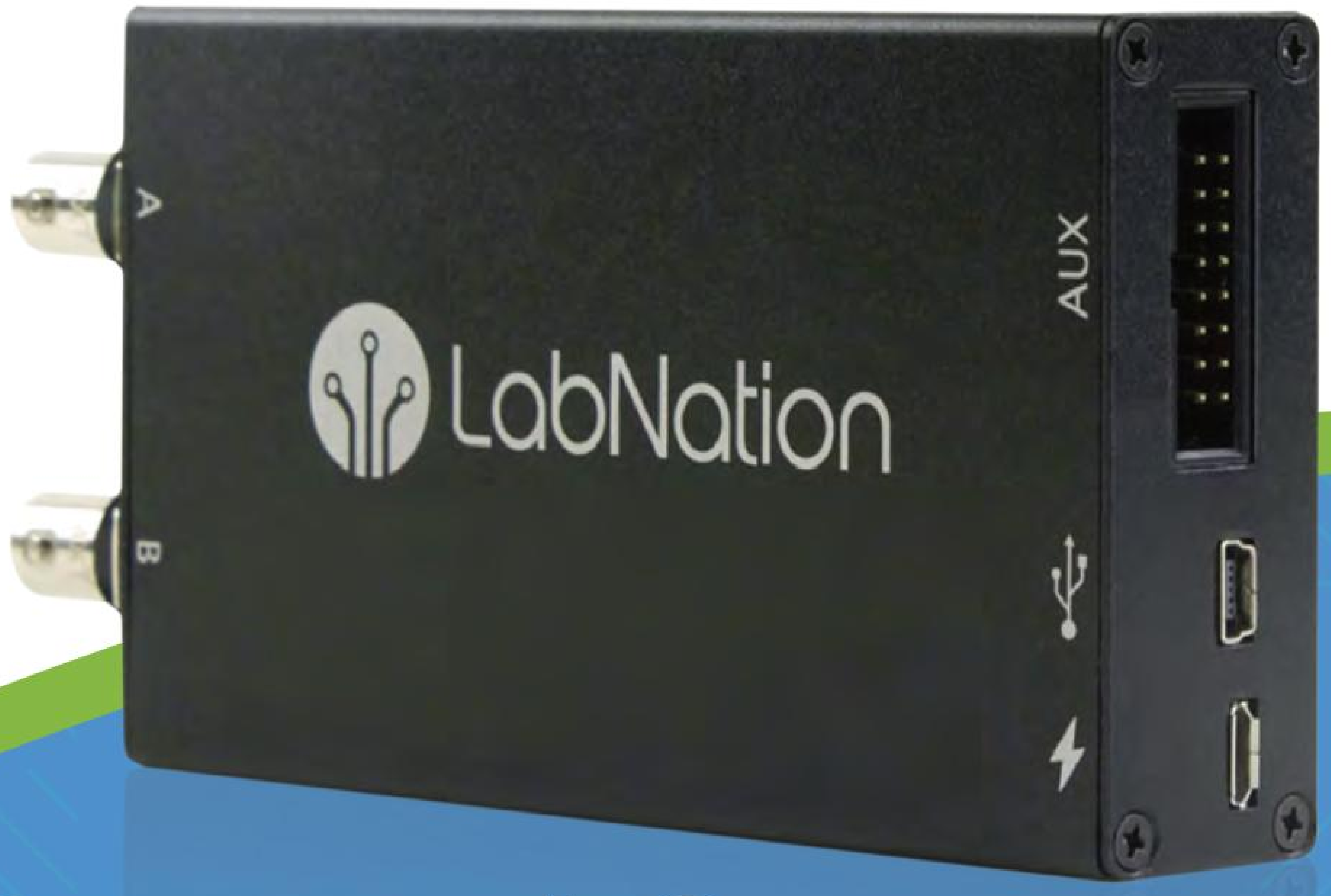
Key Features:

- 24-bit stereo audio codec
- Integrated 802.11 b/g wireless module
- Low-cost Bluetooth HCI transceiver
- Optional EBI SRAM memory
- 4.3″ WQVGA PCAP touch display daughter board
- microSD slot
- mTouch® sensing solutions buttons
- Analog temperature sensor
- VGA camera
- PICtail™ connector

Order Your Multimedia Expansion Board II
Today at: www.microchipdirect.com

The Microchip name and logo, PIC and mTouch are registered trademarks and PICtail is a trademark of Microchip Technology Incorporated in the U.S.A. and other countries. All other trademarks mentioned herein are the property of their respective companies. © 2017 Microchip Technology Inc. All rights reserved. MEC2140Eng01/17

LabNation


A
B
LabNation
AUX

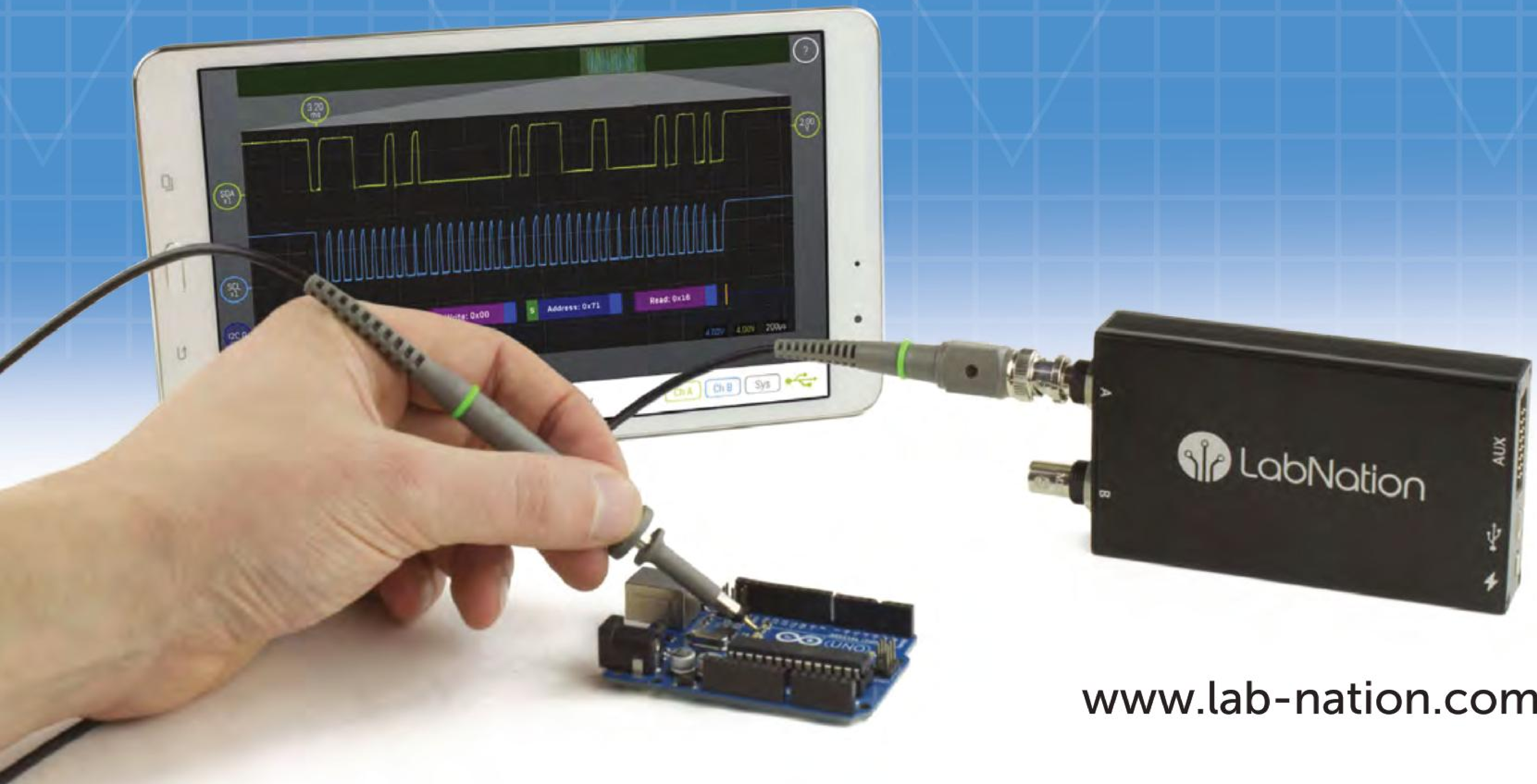
SmartScope

Compatible with laptop, tablet & smartphone

100% mobile with single wire connectivity

Intuitive touch interface

Benchtop performance in your pocket


Write: 0x00
Address: 0x71
Read: 0x16
Ch A
Ch B
Sys
A
B
LabNation
AUX
UNO

www.lab-nation.com